Tactical planning in engineer-to-order environments

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ABSTRACT

Tactical planning is implemented to balance customer demand and supply capacity within a medium-term and to avoid under- and overcapacity. In engineer-to-order (ETO) environments, under- and overcapacity lead firms to incur substantial costs that can easily wipe out profit margins. ETO-oriented markets like the construction and capital goods sectors are massive in terms of investments and have considerable impact on the gross domestic product (GDP) of nations. This makes demand-supply (DS) balancing highly important in ETO contexts.

The purpose of the thesis is to expand the knowledge about how tactical planning contributes to balancing customer demand and supply capacity in ETO settings. This purpose departed from accepting that – based on extent literature – such knowledge about tactical planning is rather generic and fragmented, which calls for further research. The results in the thesis are presented from literature studies, two single case studies and a multiple case study. Since DS balancing in principle means dealing with the complexity stemming from demand and supply, the thesis results focus on how tactical planning manages such complexity in ETO environments.

A single case study, focusing on tactical-level planning activities, together with a multiple case study, focusing on cross-functional integration, address how informal tactical-level planning processes contribute to DS balancing. Including a single case study, focusing on S&OP as a formal tactical-level planning process, the three studies form the empirical base of a framework that responds to the purpose of the thesis. The framework considers complexity, which is represented by two dimensions including detail and uncertainty.

The thesis contributes to practical aspects by providing guidance to tactical-level planners in ETO environments concerning the areas of improvement to consider when configuring and upgrading the planning process to manage complexity. The theoretical contribution of the thesis is concerned with the developed framework that describes the relation between tactical planning, DS balancing, cross-functional integration and complexity in ETO settings.

Key words: Tactical planning, Engineer-to-order, Complexity, Cross-functional integration, Sales and operations planning, Case study

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List of appended papers

Paper I:

Shurrab H., Jonsson, P., and Johansson, M. I. (2019). *"Engineer-to-order complexity in tactical demand-supply planning"*. Working paper to be submitted to *Production Planning & Control.*

An earlier version of this paper was published in the Proceedings of the 24th EurOMA Conference, 1-5 July 2017, Edinburgh.

Paper II:

Shurrab H., Johansson, M. I., and Jonsson, P. (2019). *"Integrative tactical planning to manage engineer-to-order complexity"*. Working paper to be submitted to the International Journal of Operations & Production Management.

An earlier version of this paper was published in the Proceedings of the 30th NOFOMA Conference, 13-15 June 2018, Kolding.

Paper III:

Shurrab H., Jonsson P., and Johansson M. I. (2019) *"Managing the dynamic needs of engineering resources through sales and operations planning"*. Accepted conference paper in the Proceedings to the 26th EurOMA Conference, 17-19 June 2019, Helsinki.

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The researcher's contribution to the papers

PAPER	FIRST AUTHOR	SECOND AUTHORS	RESPONSIBILITIES
1	Hafez Shurrab	Mats I. Johansson and Patrik Jonsson	The paper was planned by the first author in consultation with the other authors. The data collection was done by the first author with coordination support from the other authors. The writing of drafts for all sections was done by the first author, but the drafts were then discussed and improved jointly. Likewise, the analysis was conducted by the first author, but the discussion that led to the final analysis and conclusions was conducted between all authors.
2	Hafez Shurrab	Patrik Jonsson and Mats I. Johansson	The paper was planned by the first author in consultation with the other authors. The data collection was done by the first author with coordination support from the other authors. The writing of drafts for all sections was done by the first author, but the drafts were then discussed and improved jointly. Likewise, the analysis was conducted by the first author, but the discussion that led to the final analysis and conclusions was conducted between all authors.
3	Hafez Shurrab	Mats I. Johansson and Patrik Jonsson	The paper was planned by the first author in consultation with the other authors. The data collection was done by the first author with coordination support from the other authors. The writing of drafts for all sections was done by the first author, but the drafts were then discussed and improved jointly. Likewise, the analysis was conducted by the first author, but the discussion that led to the final analysis and conclusions was conducted between all authors.

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1 Introduction

This thesis addresses tactical planning mainly in terms of processes and cross-functional integration (CFI) considering the complexity generated from engineer-to-order customer demand and supply capacity.

The following section sheds light on the background behind the problem in section 1.1 and introduces the purpose and scope of the thesis resulting from the problem in section 1.2. Section 1.3 addresses three research questions, while section 1.4 outlines the thesis contents.

1.1 Background

Tactical planning serves as a series of decisions and scenarios for how companies' strategic long-term objectives can be achieved within shorter horizons, i.e. within the medium term.

The main objective of tactical planning is to maintain a balanced customer demand and supply capacity within a tactical medium-term timeframe, which can extend up to two years (Jonsson and Holmström, 2016). Tactical planning is a combination of decision-making and problem-solving activities aimed at balancing demand and supply.

The importance of demand-supply (DS) balancing is reflected by the relatively high costs incurred when under- or overcapacity occurs. The DS balance state is obtained when the supply capacity of a firm matches the customer demand of a targeted market in terms of volume and timing, i.e. when supply can just fulfil demand. When the supply capacity is far beyond the capacity needed to fulfil customer demand, a firm's resources become underutilised. That is, the cost of unnecessary excess resources will be incurred. When a firm is not able to meet customer demand due to supply capacity constraints, a part of relevant customer demand will be excluded, which increases the loss of business in terms of opportunity cost.

ETO-oriented products (e.g. buildings, infrastructure, ships, etc.) are characterised by high heterogeneity in customer needs, which obliges ETO companies to develop specific product designs for every single incoming customer order (Gosling and Naim, 2009; Bertrand and Muntslag, 1993). Simply put, ETO companies do not develop product designs – and in many cases do not adapt the corresponding manufacturing systems – until they receive a customer order, enquiries or contract. Therefore, tactical planning in ETO settings needs to address the engineering phase – i.e. product and production development – of the delivery process of individual customer orders.

The need of engineering activities when planning future customer orders arriving within the medium-term increases the detail and uncertainty that need to be processed in tactical-level planning activities. This is because considerably more decisions need to be made and more complex problems need to be tackled and solved. Figure 1.1 shows that on top of determining the product volumes to be fulfilled and the capacities per site to be established, tactical-level planning activities in ETO settings need to validate new customer orders and secure the capacity capable of customising product and production designs as per customer order.

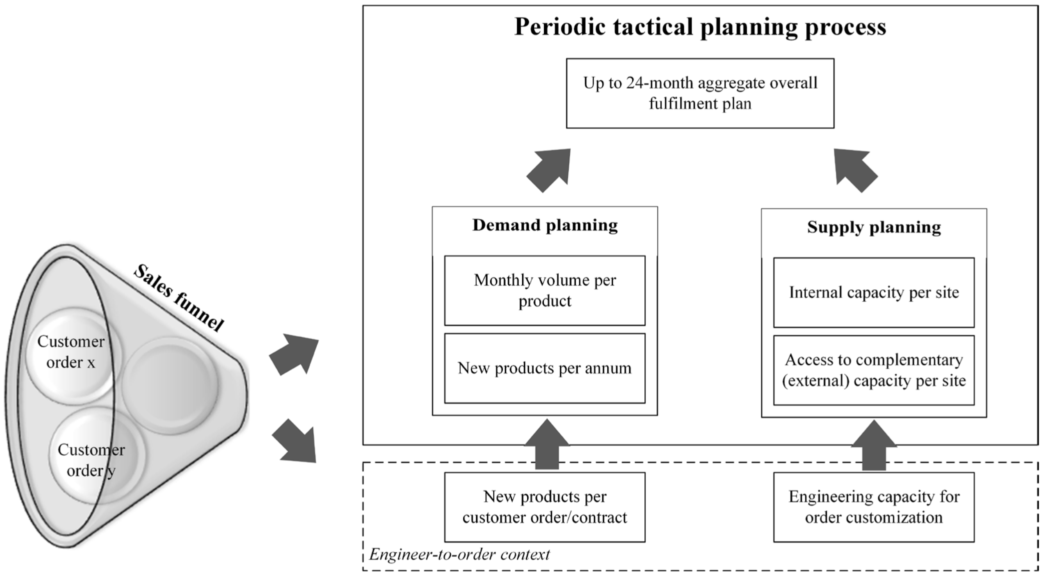

Figure 1.1 ETO-specific tactical-level planning activities

According to Carvalho et al. (2015), ETO companies need to assess each incoming customer order in terms of technical and economic feasibility, as well as strategic relevance, before providing any promises of delivery due to the high heterogeneity embedded in customer needs that call for substantial customisation. This means that tactical planning in such contexts not only needs to address decisions concerning demand and supply from a high-level multi-project perspective, i.e. counting customer orders as mere numbers of products consisting of standard components), but also needs to include decisions and develop clear solutions concerned with individual projects. For instance, in the construction industry, customer order fulfilment starts by order screening and prioritisation considering several criteria such as profitability, financial and technical risks, the influence on resource utilisation, project and critical resource location, etc. (Ravanshadnia et al., 2011). Therefore, the decision-making and problem-solving scope in ETO settings is relatively broad and the level of related uncertainty is considerably high (Gosling et al., 2015; Hicks et al., 2000; Little et al., 2000). This is reflected in the relatively high number of variables usually embedded in an ETO setting when studying customer enquiries since the degrees of product customisation allowed for customers are relatively high.

Consequently, the way a tactical-level planning process is configured to ensure DS balancing in ETO settings is noticeably constrained by more requirements compared to contexts with less variability, where formalised processes like sales and operations planning (S&OP) are common. For instance, because it is technically infeasible to store many ETO products (Olhager, 2010), the planning focus is shifted towards customer order backlogs instead. In less uncertain environments like make-to-order (MTO) settings, product boundaries are more specific and tactical planning focuses on the inventories of the materials, components and subsystems that must be available – not engineered – to enable the different types of MTO products to be built. Even if ETO products can be stored, their holding costs are not negligible (Hicks and McGovern, 2009). Above all, ETO products are often customised to meet the specific needs of certain customers and, thus, difficult to be sold otherwise.

Given the additional engineering cost and time added to the delivery process, any slight difference between customer demand and supply capacity in ETO settings often leads to financial issues (Olhager, 2010). Accepting a few more customer orders than what a firm can handle will result in time delays (which often leads to substantial penalties), not to mention the consequent customer dissatisfaction. On the other hand, excluding more customer orders than what would ensure proper utilisation of critical resources will prevent the unlocking of advantageous profit margins. This is because the criticality of resources not only stems from the special capability they provide to enhance the overall capacity, but also stems from the lack of resources and the difficulty to compensate for such resources in a timely fashion. Therefore, planning the medium-term demand and supply, i.e. at the tactical level, is important from a strategic perspective to fulfil the ultimate business objectives.

Though tactical planning received high recognition in operations management literature, especially as a part of a hierarchical structure (e.g. Miller, 2012; Jonsson and Mattsson, 2009; Hans et al., 2007; Mula et al., 2006), a consensus on tactical-level planning activities applicable for ETO settings is still lacking. Instead, tactical planning is shaped and uniquely structured depending on the specific type of context that applies with less consideration for the transferability across different ETO settings. For instance, S&OP is largely considered as an integrated collaborative tactical-level planning process that combines master production and demand plans to balance demand and supply within the medium term (up to 24 months) (Jonsson and Holmström, 2016). However, the way S&OP is adapted to fit a specific setting varies across different contexts and how S&OP manages DS balancing in ETO settings is understudied (Kristensen and Jonsson, 2018). Above all, very limited research addresses S&OP-like processes whereby tactical-level planning activities are at least informally integrated to ensure the balance between demand and supply in ETO settings. Perhaps, such a process needs to fulfil certain prerequisites to manage the complexity embedded in ETO demand and supply. Exploring such prerequisites needs in-depth studies that capture the specific factors that drive complexity and the mechanisms leveraged by the tactical-level activities to balance demand and supply.

Very few studies addressed the tactical-level planning domain in ETO settings. Most of the studies of relevance tried to develop optimisation models through objective functions that either minimise cost (e.g.Tolio and Urgo, 2007; Gademann and Schutten, 2005; Márkus et al., 2003) and timespan (e.g. Nobibon et al., 2015), or maximise revenue (e.g. Alfieri et al., 2012). Other studies like the work of Carvalho et al. (2015) include more variables and more explicitly address DS balancing as a main objective, but still with a focus limited to the quantifiable aspects of the process.

1.2 Purpose and scope of the thesis

The next three sections discuss the purpose, the scope and the research questions of the thesis.

1.2.1 Purpose

From a hierarchical perspective that divides planning into three horizons including strategic long-term, tactical medium-term and operational short-term planning (see O'Reilly et al., 2015; Miller, 2012; Hans et al., 2007; Hax and Meal, 1973); explicating the influence of tactical-level planning activities on detail and uncertainty in a certain context is arguably important for both theory and practice. Tactical planning serves as a transition between strategic and operational planning and exploring tactical-level planning activities helps to understand the underlying prerequisites to balance demand and supply. Even though the extant literature largely agrees on balancing demand and supply being the main objective of tactical planning, the ways through which such balance is obtained are arguably different across different contexts, given the contextual differences in terms of the levels of detail and uncertainty that tactical-level planning activities need to tackle.

Balancing customer demand and supply capacity through tactical planning in ETO companies implies dealing with considerably greater complexity, represented by the increasing level of detail and uncertainty. From a practical perspective, identifying tactical-level planning activities and exploring their influence on DS balancing provide tactical-level planners (e.g. product-portfolio managers, resource planners, recruiters and human resource managers, master production managers, etc.) with further insights into the types of activity-related uncertainties. Identifying such uncertainties guides the efforts dedicated to improving the communication flows and related information support systems so that decision makers are provided with more timely facts and evidence and are left to less speculation and rough estimates when making decisions.

As discussed earlier, the complexity in ETO settings increases due to the need to actively change product designs – if not the underlying production systems too – to fulfil the requirements of individual customer orders (Gosling and Naim, 2009; Hicks et al., 2001). Consequently, either the existing production systems are recurrently adapted to live up to the specifications provided in the new contracts with customers (e.g. aerospace manufacturing) or new production systems are regularly established, introduced and dedicated to individual customer orders (e.g. the construction industry). Therefore, *the purpose of this thesis is to expand the knowledge about how tactical planning contributes to balancing customer demand and supply capacity in ETO settings*, as shown in Figure 1.2. Supply capacity represents the capacities of all individual resources that a firm possesses or has access to.

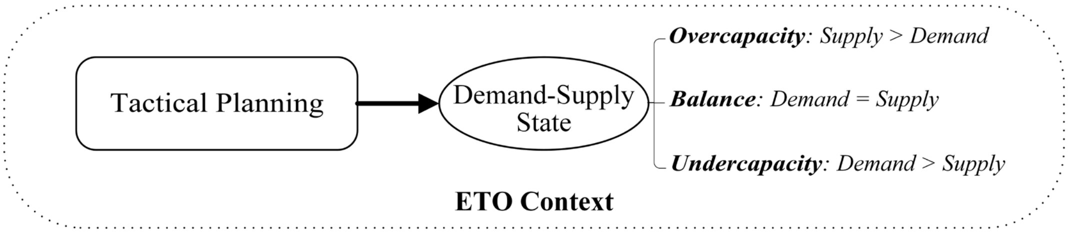

Figure 1.2 Purpose of the thesis

1.2.2 Scope

This thesis addresses planning activities and the mechanisms applied to them to manage the complexity stemming from ETO demand and supply so that neither under- nor overcapacity occurs. Particularly, tactical-level planning activities, complexity, cross-functional integration (CFI) and S&OP represent the scope elements of the thesis.

Tactical-level planning activities are divided into two types: decision making and problem solving. To match demand with supply over extended time horizons, issues and challenges are encountered, some of which are captured by problem-solving activities. In problem-solving activities, the DS balancing problems are first identified, and relevant alternative solutions/scenarios are then generated. Here, decision-making activities come into play, where the most fulfilling solutions are selected given certain criteria. Drawing on the notion discussed by Anthony (1965), management decisions can be related to operational, tactical or strategic levels depending on their impact. That is, whether a decision has a tactical influence or not is decided by whether the corresponding impact extends beyond the operational short-term horizon. This means that the focus of this thesis is limited to the problem-solving and decision-making activities that have a tactical impact, i.e. at a tactical level. Particularly, the problem-solving and decision-making activities that can be related to medium-term DS balancing are focused on, since DS balancing serves as the main objective for formal tactical-level planning processes at an aggregate level (Jonsson and Holmström, 2016).

Since limited research exists concerning DS balancing as a focal phenomenon, theories about supply chain complexity are borrowed to explore the impact of tactical solutions and decisions on DS balancing. Many studies divide complexity into two dimensions: detail and dynamic complexity (see Bozarth et al., 2009). Detail complexity describes the number of variables captured in a context, while dynamic complexity describes the situations where effects cannot be observed until causes are gradually accumulated (Senge, 1998). This definition reflects how uncertainty acts as a core element of dynamic complexity. Having already been largely discussed in literature (e.g. Galbraith and Buck, 1977), uncertainty in this thesis is used as a variable that captures dynamic complexity. Further, detail and uncertainty are assumed to characterise demand and supply planning.

Another important area considered in this thesis is CFI. CFI represents the essence of formalised tactical-level planning processes like S&OP through which DS balancing is facilitated. The thesis addresses the CFI mechanisms reflected by tactical-level planning activities that can influence the detail and uncertainty stemming from ETO demand and supply. Integration as conceptualised by Kahn (1996) is adapted, where integration is perceived as interactions that either reflect coordination or collaboration. Coordination provides structure to interactions, while collaboration represents the affective behaviour of interacted or interacting parties such as mutual trust. Only coordination is addressed in the thesis. Above all, tactical planning serves as a compilation of coordination mechanisms (e.g. Tuomikangas and Kaipia, 2014).

The thesis explores the ETO contexts where tactical planning is formalised within an integrated process. Here, S&OP comes into play as a good example that is not common in ETO settings. Therefore, the thesis addresses an ETO case where S&OP is implemented. S&OP is a process for developing tactical-level plans that enable managers to strategically direct businesses to continuously achieve competitive advantage by matching customer-focused marketing plans for new and existing products with supply chain management (Blackstone Jr., 2010). S&OP is, therefore, an integrative process that allows for substantial cross-functionality within decision-making and problem-solving activities (Thomé et al., 2012; Oliva and Watson, 2011). This thesis particularly addresses the uncertainty areas associated with engineering resources in an ETO environment and how the S&OP process is influenced and manages such uncertainty. The influence on S&OP is studied in terms of the S&OP maturity dimensions including people and organisation, processes and methods, performance measurement and information technology (IT) (Danese et al., 2017). The generic process model of S&OP is derived from extant literature (e.g. Wallace and Stahl, 2008). Five stages are mainly incorporated including data gathering, demand planning, supply planning, pre-meeting and an executive meeting.

1.3 Research questions

This thesis is structured to answer three main research questions and to align the work with the purpose presented in section 1.2. The motivation of each research question is discussed and presented to provide an overview of the relevance of each question. More detail with respect to the relevance of each question is provided in the theoretical framework described in Chapter 2.

Although the three questions have different foci, they still have aspects in common. All questions consider the relationship between tactical planning and DS balancing in an ETO setting. Due to the lack of ETO companies that implement formal tactical-level planning processes like S&OP, the first two questions address tactical-level planning activities as they are implemented within related processes. On the other hand, the third question addresses S&OP as a reference model for formal tactical-level planning processes as the generic model of S&OP process clearly addresses DS balancing through decisions and activities, which is arguably less structured otherwise. Therefore, the first two questions address the complexity stemming from ETO demand and supply.

Answering the three questions thereby provides insights into how tactical planning contributes to DS balancing in ETO environments. Such insights are synthesised into theoretical frameworks that help to further understand how to facilitate DS balancing. Accordingly, the results derived from the questions are intended to be of benefit beyond the thesis boundaries.

1.3.1 Research Question 1

Previous studies have not adequately captured the domain of tactical planning in ETO settings and there is a need to first identify the decisions and activities relevant to DS balancing. The extant research partly addresses the impact of several decisions within processes of tactical relevance in ETO organisations emphasising the optimality of respective decision configuration (e.g. Carvalho et al., 2015; Nobibon et al., 2015; Alfieri et al., 2011; Tolio and Urgo, 2007; Gademann and Schutten, 2005; Márkus et al., 2003). However, very few studies investigate tactical-level decisions in terms of their impact on complexity when balancing demand and supply, i.e. the complexity stemming from demand and supply.

As adapted from Senge (1998), complexity can be expressed in terms of detail and uncertainty. That is, the more detail about customer demand (e.g. number of customers) or supply capacity (e.g. number of resources), or the more the uncertainty of customer demand (e.g. demand variety) or supply capacity (e.g. lack of supplier reliability), the higher the complexity when balancing demand and supply. Therefore, capturing how tactical-level decisions can reduce the overall detail and uncertainty is important for DS balancing, since the higher the detail and uncertainty, the higher the coordination needed to match demand and supply (Bozarth et al., 2009).

The lack of such research is arguably due to tactical-level planning activities and decisions not being adequately identified and structured as an integrated sequence of events that guides decision making in ETO settings. Therefore, to fill such a theoretical gap, the first question targets the link between certain planning activities and tactical planning through the evidence of the decision impact on DS balancing, which is formulated as follows:

Research Question 1:
How does ETO complexity affect the balancing of customer demand and supply capacity in tactical planning, and how is ETO complexity managed in the tactical-level planning process?

1.3.2 Research Question 2

Formal tactical-level planning processes like S&OP act as an integrative mechanism aiming to balance demand and supply. Therefore, in contexts where formal integrative processes are lacking, capturing the integrative role of corresponding activities is important. This helps to gain more understanding for how CFI facilitates DS balancing in ETO settings. DS balancing is assumed to be represented by relevant decision-making and problem-solving activities.

A few studies addressed CFI within tactical-level planning processes. One such effort is the work of Oliva and Watson (2011) who more specifically investigated the cross-functional integrative role of tactical planning through studying sequenced activities in detail. Nevertheless, their case company does embed ETO orientation.

Like the first research question, the effect of CFI mechanisms on DS balancing is inferred through the effect on the detail and uncertainty stemming from demand and supply. The notion of CFI is mainly based on information processing. In a planning context, information represents the input that needs to be processed (encoded to give meaning and compared with stored information) by individuals working on planning tasks to generate solutions and enable assessments of these solutions (Rogers et al., 1999; Simon, 1978). Having proposed a reference model for tactical planning in ETO settings to answer the first research question, the second research question targets the link between CFI mechanisms and the uncertainty and detail stemming from demand and supply. Accordingly, the second research question is formulated as follows:

Research Question 2:
How can the cross-functional integration of tactical planning manage the complexity stemming from ETO demand and supply?

1.3.3 Research Question 3

A S&OP process is ultimately aimed at DS balancing. However, the way S&OP is configured and implemented seems to vary depending on context (Thomé et al., 2012). For instance, in the food industry, planning horizons and frequencies need to be adapted to the seasonality and perishability of products (Kjellsdotter Ivert et al., 2015). This means that companies need to learn how the S&OP process should be adapted to produce the intended effect (i.e. attain the DS balance) and to fit the intended context.

Most of S&OP research addresses supply settings with make-to-stock, assemble-to-order or make-to-order orientations; but very limited attention has been given to ETO settings (see Kristensen and Jonsson, 2018). Arguably, this is due to the lack of ETO-oriented firms that use S&OP. Theoretically, exploring how ETO-oriented firms manage the ETO-specific complexity using S&OP helps to identify the requirements in the S&OP process and the extent to which it manages the complexities in this context. Particularly, the complexity stemming from the high levels of uncertainty associated with the medium-term needs of engineering resources needs more attention. This is because engineering resources are more frequently needed in ETO settings due to the high customisation orientation. That is, securing the engineering resources that will be required within the medium term is very important to fulfil customer demand in ETO settings.

Practically, explicating enablers and barriers concerned with S&OP in ETO settings encourages other ETO-oriented companies to further formalise and structure the corresponding tactical-level planning activities accordingly. As such, the third question addresses the link between S&OP and one of the main ETO-specific areas of complexity, i.e. the uncertainty concerned with engineering resources, which is formulated as followed:

Research Question 3:
How does S&OP manage the complexity associated with engineering resources in an ETO environment?

1.3.4 Conceptual framework of the thesis

The conceptual framework in Figure 1.3 shows how the three research questions are positioned to contribute to the purpose of the thesis. The arrows of RQ1 and RQ3 focus on the bidirectional influence between the complexity and the tactical-level decisions and activities, and the complexity and CFI, respectively. The complexity represents the detail and uncertainty stemming from demand and supply that need to be managed to avoid the states of under- and overcapacity, which is in line with the purpose of the thesis. The framework shows that the way tactical planning facilitates DS balancing is subjected to the contextual influence of an ETO environment.

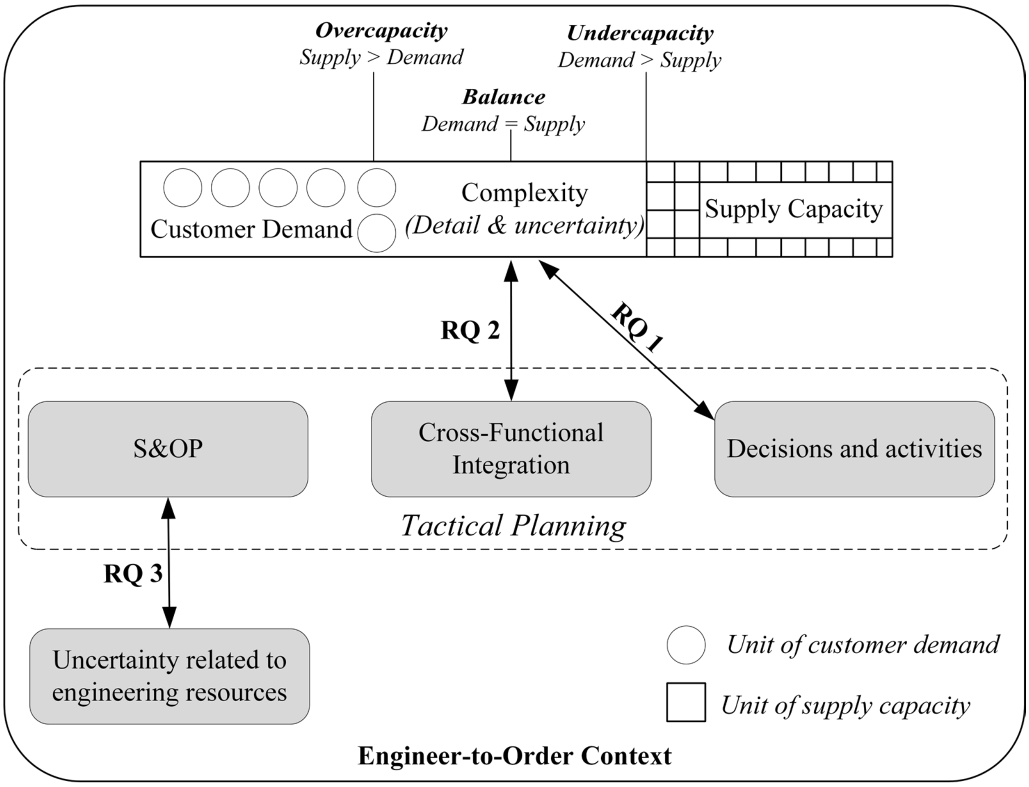

Figure 1.3 The conceptual framework of the thesis

1.4 Outline of the thesis

Chapter 1 presents the background of the thesis, including the problem addressed, the purpose and scope of the thesis, the associated three research questions and the respective conceptual framework.

To explain the theoretical framework of the thesis, Chapter 2 is organised around five primary topics: tactical planning, complexity, S&OP, CFI and the synthesis of those elements in the theoretical framework of the thesis.

Chapter 3 presents the research method of the thesis and describes the efforts dedicated for ensuring the quality of the research conducted to answer the research questions.

Chapter 4 presents a summary of the three appended papers for the reader's reference.

Chapter 5 presents the answers to the three research questions, i.e. the results of the thesis.

Chapter 6 discusses the results of the thesis highlighting the contributions to the research purpose and related transferability and outlining directions for future research.

Chapter 7 presents the conclusions of the research.

2 Theoretical framework

This chapter presents the theoretical framework of the thesis. Section 2.1 defines “tactical planning”, presenting its historical role, and discusses aspects of the tactical planning environment addressing several dedicated activities. In the sections that address the environment of tactical planning, the term “complexity” is defined and discussed in more detail presenting the two main types of complexity and several associated drivers that typically exist in supply chains. In the sections that address the tactical-level planning activities, “sales and operations planning” is reviewed in terms of the planning setup, process, environment variables and maturity dimensions. Section 2.2 defines “integration” as a concept, discussing the difference between achieved integration and the status of being integrative. Further, the conceptual model of integration proposed in previous studies is adapted, and the concepts of “interaction”, “coordination” and “collaboration” are defined accordingly. Next, several integrative coordination mechanisms are defined and presented including "centralisation”, “standardisation”, "formalisation”, “cross functional teams”, “individual integrators”, “task design” and “information systems”. Finally, section 2.3 synthesises the relevant theory into the complete conceptual framework used in the thesis, combining the different frameworks of relevance derived from section 2.1 and 2.2, as shown in Figure 2.2.

2.1 Tactical planning

A central term in the thesis is *tactical planning*, a term consisting of two words, each with a specific meaning. This section aims to clarify this term by first defining planning in general, before defining the impact of adding the term “tactical” to the definition of planning. Then, the role of tactical planning is reviewed. The section continues with details about the impact of the environment on tactical planning discussing the influence of supply chain complexity. The section ends with a review of sales and operations planning and related aspects.

2.1.1 Tactical planning: definition and role

In basic terms, planning is “*the act of deciding how to do something*” (Walter, 2008, p.1080). In a business context, planning is “*the process of deciding the activities or events in an organized way so that they are successful or happen on time*” (Combley, 2011, p. 633). That is to say, planning is about deciding what activities to carry out in the future, how and when they will be performed, and which resources to use to achieve which goal(s).

In a production context, planning frequency, planning horizon and planning object all represent generic planning setup parameters (Jonsson and Mattsson, 2009). Planning frequency represents how often the respective decision-making process is conducted, while the planning horizon describes the period into the future a plan may cover. A planning object represents the entity on which most of the decisions are made, which can be final products, product families, stock-keeping units (SKUs) or combinations of these types.

The fact that management decisions have different impact horizons shapes the basis on which hierarchical production planning (HPP) is organised (Anthony, 1965). For instance, the decisions that have clear long-term impact constitute strategic planning, while the decisions that have an impact on shorter horizons constitute tactical and operational planning.

Strategic decisions are generally concerned with managerial policies and competence developments that help to satisfy the target market over the long term, which usually involve large investments (Liberatore and Miller, 1985). Strategic decisions lead to shaping the competitive position and growth rate of the firm towards long-term business success. In contrast, operational decisions deal with day-to-day tasks, which require pre-set objectives at higher levels to be completely disaggregated into equivalent operational performance objectives (Bitran and Tirupati, 1993).

As for the decisions related to tactical planning, the focus is primarily on resource utilisation, and the planning object is typically aggregated into product families (Bitran and Tirupati, 1993). In line with this, several studies of operations management (e.g. Kristensen and Jonsson, 2018; Tuomikangas and Kaipia, 2014; Thomé et al., 2012), operations research (e.g. Carvalho et al., 2015; Aghezzaf et al., 2010) and supply chain management (e.g. Jonsson and Holmström, 2016; Oliva and Watson, 2011) agree on DS balancing being the focus of tactical production planning. DS balancing helps to achieve business objectives through ensuring that operations over a medium-term horizon (1 month to 2 years) deliver the desired results that fulfil strategic objectives and that strategic objectives are updated consistently with the firm's operational capabilities. When developing a tactical plan, planners need to control variables like output rates, utilisation levels and subcontracting to meet predictable demands at the lowest possible total cost (Aghezzaf et al., 2010).

2.1.2 Tactical planning environment

As reviewed earlier, the planning steps that address future activities within tactical horizons are mainly concerned with sales, resource utilisation and throughput. These steps serve as sub-processes in an aggregate tactical-level planning process that primarily aims to balance customer demand and supply capacity aiming to achieve the strategic alignment throughout the vertical organisational levels. In other words, a tactical-level planning process makes decisions concerning the dimensions of customer demand and supply capacity in medium terms guiding the way relevant day-to-day activities should be performed and prioritised.

However, tactical planning – as an aggregate process and setup – varies depending on the environment in which planning is conducted (Kjellsdotter Ivert et al., 2015; Jonsson and Mattsson, 2003). Presumably, the variables stemming from planning environments which can influence tactical planning can be related to complexity. Planning in different contexts varies in terms of the amount of aspects or details to be considered and the availability of relevant information, commonly termed as complexity. In other words, the complexity of a certain context enforces certain prerequisites concerning how planning can be performed. And since tactical planning addresses DS balancing, identifying the complexity driven by demand and supply helps to generally understand how the prerequisites of tactical planning change as the planning environment changes.

Bozarth et al. (2009) introduced a generic framework that can capture complexities in supply chains. According to the framework, complexity is driven from downstream, upstream or internal manufacturing. The complexity drivers either increase the number of variables – or detail – captured in a context (termed as *detail complexity*) or increase the situations where effects cannot be observed – due to increased uncertainty – until causes are gradually accumulated (termed as *dynamic complexity*) (Senge, 1998). That is, the complexity drivers either increase detail and dynamic complexity, which are presumably captured by detail and uncertainty as respective characteristics. The greater the amount of detail to address and the greater the planning detail (or interactivity) is, whereas the more ambiguous the causality in a context, the higher the uncertainty a plan should deal with. The difference between detail complexity vs detail, and dynamic complexity vs uncertainty, is that the complexity dimensions are endogenous to the context, while both detail and uncertainty are exogenous and can be – at least theoretically – controlled through coordination settings (Tuomikangas and Kaipia, 2014). And since planning is about making decisions, higher coordination levels are usually needed as both detail and uncertainty increase.

Downstream complexity drivers include the number of customers, heterogeneity in customer needs and demand variability. According to Berry et al. (2011), more customers lead to more tasks for customer relationship management, demand and order management; which all increase detail. In turn, targeting a greater variety of customer needs blurs the fulfilment of the strategic priorities (i.e. order winners and qualifiers) that should be strived for and how manufacturing tasks should be aligned accordingly (da Silveira, 2005). Instead, the scope of business operations should be limited to the solutions for which the firm has high technology readiness levels, i.e. where the underlying technologies are mature and can be consistently used to fulfil the predefined purpose (Mankins, 2009).

Depending on the levels of demand, supply chain actions can lead to different outcomes such as stockout, and greater variability in demand increases the uncertainty upstream. For instance, a lack of coordination along supply chains in ordering polices causes the bullwhip effect where fluctuations in upstream ordering patterns grow as downstream demand suffers a slight variability over time (Chen et al., 2000).

Internal manufacturing drivers include the number of products, number of parts, low volume batch production and manufacturing schedule instability. An increase in the number of products and the underlying unique parts leads to an increased variety of manufacturing tasks (Closs et al., 2008; Salvador et al., 2002), which increases detail. Low volume batch production or the so-called one-of-a-kind production increases the number of unique jobs in manufacturing leading to a higher detail. Moreover, this high degree of uniqueness across jobs causes variability in the underlying manufacturing tasks leading to greater uncertainty, which is often dealt with through increasing the cross-functional interactions in the plant (Hill, 2017; Duray et al., 2000). According to Berry et al. (2011), instability in a production environment is driven by factors like unexpected absenteeism and machine failure, which increases the uncertainty of production schedules. Manufacturers dedicate planning and control systems not only to deal with the uncertainty originating from such unpredictability and the non-linear impacts on lower-level production and material plans, but also to deal with the uncertainty related to the cross-functional interactions required to link production plans and execution activities.

Complexity is also driven by upstream drivers including the number of suppliers, long and/or unreliable supplier lead times and globalisation of the supply base (Bozarth et al., 2009). Adding suppliers or generally external contributors necessarily increases not only the number of information flows, physical flows and relationships that must be managed, but also the uncertainty related to their lead time performance. Long and/or unreliable supplier lead times lead to longer planning horizons and greater levels of detail, which increases the underlying uncertainty in the supply chain (Berry et al., 2011). Finally, the growing globalisation of a supply base increases the uncertainty in, for instance, import/export laws, fluctuations in currency valuations, cultural differences and longer and (eventually) more uncertain lead times (Cho and Kang, 2001).

Since this thesis addresses DS balancing from an internal perspective, downstream complexity drivers are related to demand as they mostly originate from the customer side, while upstream and internal manufacturing complexity drivers are related to the supply side. Therefore, the complexity drivers are instead assumed to stem from demand or supply. In short, the way tactical planning is performed and set up depends on the degree of detail and ambiguity stemming from customer demand and supply capacity. In line with this, the next section sheds light on typical tactical-level planning activities arranged in ETO environments, where complexity can be considerable.

2.1.3 Tactical planning in ETO environments

ETO environments are characterised by high degrees of product customisation and large investments required to deliver customer orders. Therefore, planning to meet ETO demand is handled through customer order management, where demand fulfilment is based on an available-to-promise (ATP) function. The ATP function provides a response to customer order enquiries based on lead time agreements and the availabilities of material and capacity (Olhager, 2010).

According to Giebels (2000), ETO tactical planning starts when customer order enquiries are selected for ATP assessments, which is labelled as the “order acceptance” stage. Order acceptance corresponds to the order entry and prioritisation stage included in Day’s (1994) generic order fulfilment process, which is a largely accepted process model for market-driven organisations. Order entry and prioritisation follows order generation, which seems to lie in the strategic phase concerned with marketing, segmentation and resource base development.

After accepting strategically fit customer orders; capacity, material and technology need to be planned through multi-project rough-cut capacity planning (RCCP), procurement (sourcing and purchasing) and macro process planning (Hans et al., 2007; Giebels, 2000). In Day’s (1994) model, these processes correspond to order scheduling, which seems to partially fall into the operational phase that deals with detailed single-order scheduling following the multi-order scheduling. Figure 2.1 adapts the HPP structure of Hans et al. (2007) and Giebels

(2000) and the fulfilment process of Day (1994) into a conceptual framework for tactical planning within customer order fulfilment.

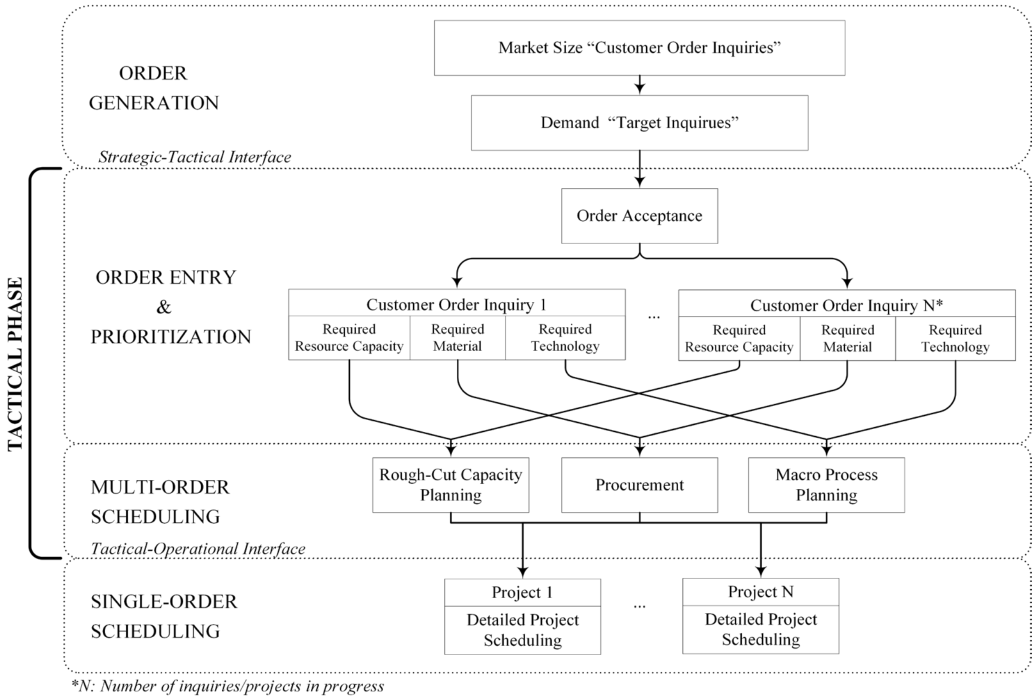

Figure 2.1 Tactical planning within customer order fulfilment

2.1.3.1 Order acceptance

ETO-oriented organisations carefully accept customer orders through ensuring that the expected revenues will exceed the extra costs of, for instance, overtime work, tool wear, material usage, etc. (Giebels, 2000). Commonly, these organisations tend to accept as many enquiries as possible and strive to promise a delivery date as early as possible to win the competition (Hans et al., 2007). However, ETO complexity levels associated with, for instance, the variability of customer enquiries (in terms of product specifications, tool requirements, material, routing, activity work content, etc.) and the dependency on common resource pools are considerably high (Hicks et al., 2000). This makes estimating the decision impact on the operational production system performance very difficult. And given that the ability to quickly price tight and reliable due dates endows ETO organisations with an outstanding competitive advantage, enquiries need to be screened, selected, prioritised and eventually accepted or rejected (Carvalho et al., 2015).

Apart from the necessity to strategically fit the firm's strategic objectives (Easton and Moodie, 1999), enquiries are generally accepted without sufficiently assessing the related impact on capacity (Hans et al., 2007). This is arguably due to the high levels of detail and dynamic complexity originating from ETO demand and supply.

The next section reviews how ETO organisations approach DS balancing considering all complexity drivers through RCCP, procurement and macro process planning.

2.1.3.2 Rough-cut capacity planning

RCCP can be either proactive or reactive. Some researchers like Wullink et al. (2004) proved considerable cost-reduction improvements through integrating scenario-based analysis into RCCP to proactively deal with system complexity like manufacturing instability. Other improvements besides cost minimisation can be the ability to set up a plan to cope with disturbances, i.e. plan robustness, which is difficult to quantify. Apart from that, reactive RCCP is another common practice among ETO-oriented organisations, which means that they apply one or more re-planning rules when disturbances occur, or simply – and more commonly – through updating an existing plan in a certain fixed frequency (Hans et al., 2007).

Giebels (2000) identified three main objectives that RCCP can address to support order acceptance: 1. verifying the manufacturing capability, 2. determining the delivery dates for the individual order enquiries, and 3. analysing the expected revenue and cost from accepting orders in view of other future potential or in-progress customer order enquiries/projects. Verifying the manufacturing capability can be done through macro process planning (reviewed in section 2.1.3.4), which helps to roughly assess the ability of a firm's resource combinations to deliver products as per specifications (Cay and Chassapis, 1997).

Estimating delivery dates requires more detailed analysis of the engineering and production work along with the impact on respective lead times. In ETO settings, engineering activities determine product and production designs and select appropriate materials and technology. In addition to material supply, planning the sourcing and purchasing of external contributions (from e.g. consultants, subcontractors, transport providers, etc.) is done through a procurement process (further discussed in section 2.1.3.3) to complement, enhance and support engineering and production (i.e. logistics and manufacturing) activities depending on the availability of and constraints on internal resources.

Allocating resources, often termed as "resource loading" (Nobibon et al., 2015), helps to identify capacity issues as per individual orders in early stages and trigger process planning when necessary to integrate its outcomes. Resource allocation mostly deals with internal manufacturing complexity drivers like manufacturing schedule instability (often caused by machine breakdowns, etc.) and low-volume or one-of-a-kind production. The latter driver increases uncertainty, which is mainly caused by the high degree of uniqueness embedded in project-based production. Uniqueness is primarily reflected as a lack of information completeness and accuracy related to all processing and lead times, which can have a major impact in this context. Therefore, the support of information technology (IT) is often needed in resource loading.

Not only do IT tools help in handling large amounts of scattered information and data for the sake of optimising resource loading effects on performance through uncertainty-aware models, but they also enable predictions of processing and lead times given the existence of relevant data from previous projects and experienced specialists (Govil and Fu, 1999). However, predicting the routings and processing times of engineering activities is usually difficult due to the lack of corresponding standard references, which implies that predicting the availability of related resources is also, if not more, difficult. Engineering activities have high interdependency and are performed by specialist labour like product designers and process engineers. Specialist labour is often costly due to their relatively high educational backgrounds, and rare due to their uniquely accumulated expertise over long years of field and office work, which is why specialists in most ETO sectors are attracted by flexible contracts. Accordingly, specialist labour unsurprisingly represents the bottleneck in ETO systems, and the ways they can be utilized vary dramatically (Giebels, 2000).

Based on the earlier discussion to determine delivery due dates, ETO organisations need to determine the lead times of internal and external engineering and production activities. To determine the latter type, more operational data like order priority, amount of work in process, routing and batching may be required (Giebels, 2000). Having the delivery dates determined, the overall costs and revenues can be estimated, but pricing in this context is still limited due to fierce competition. ETO organisations however tend to highly exploit non-regular capacity (e.g. subcontracting) at a multi-project level by making trade-offs between the acquisition cost of non-regular capacity and gained performance benefits (Gademann and Schutten, 2005). This can be done through, for instance, balancing critical resource allocation over customer orders, which eventually leads to earlier delivery dates and higher quality (Cooper and Budd, 2007).

2.1.3.3 Procurement: sourcing and purchasing

Acquiring extra capacity, material, technology and transportation in an ETO environment is driven by actual customer demand as inventory often becomes an infeasible option (Olhager, 2010), meaning that timeliness is necessary for procurement. Moreover, to deal with the high demand-related complexity, upstream complexity normally increases linearly through, for instance, an increased number of suppliers, increased lengths and/or unreliability of supplier lead times, and increased globalisation of the supply base.

At a tactical level, procurement in ETO organisations like construction contractors lack strategic partnering with a relatively small number of suppliers (Sabolová and Tkáč, 2015). Strategic partnering can provide cost, quality and flexibility benefits. Accordingly, sourcing and purchasing activities can lead to extra time and process requirements if not appropriately planned early on at an aggregate level. Above all, the decisions made throughout the sourcing and purchasing processes can influence the overall costs, product specifications and delivery due dates, which is the reason why procurement is a fundamental tactical process in this context.

2.1.3.4 Macro process planning

Giebels (2000) claims that ETO manufacturing processes should be planned within the tactical phase at least at a macro level to deal with the relatively high detail and dynamic complexity. Macro process planning is concerned with the selection of manufacturing processes and conducting related manufacturability analysis, while macro process planning includes selecting and sequencing operations and generating optimal process plans (Cay and Chassapis, 1997).

Allocating certain technological and logistics resources, determining routing, and outsourcing require specialist process knowledge, which means that macro process planning must concurrently support RCCP in dealing with the complexities driven by internal manufacturing (e.g. manufacturing schedule instability), demand (e.g. variability of customers and orders), and/or supply (e.g. variability of supplier lead times). This is because having complete information about all production orders, routings and processing times at a tactical level is in practice almost impossible using hierarchical manufacturing (Giebels, 2000).

2.1.4 Formally integrated tactical planning: sales and operations planning

Gelders and Van Wassenhove (1982) claim that tactical-level planning activities can – through inter-departmental coordination – integrate the firm's activities across hierarchical levels, i.e. vertically from strategic to operational levels and horizontally across organisational functions. Vertically, tactical-level planning objectives must be disaggregated from the firm's strategic objectives so that they are aligned with business priorities and marketing plans, and the firm's core competitive capabilities. At the same time, tactical-level objectives should capture the performance of day-to-day activities through having them integrated into corresponding high-level indicators, which in turn need longer time horizons to be elicited such as resource utilisation and hit-rate. Such indicators help to either control customer demand or supply capacity in the pursuit of an in-between balanced state.

Like HPP, material planning and control (MPC) is more addressed in recent literature as a system that links manufacturing processes across strategic, tactical and operative levels. Within the MPC system, the planning horizons, planning objects and frequencies differ across the planning levels, where the higher up the MPC hierarchy, the longer the planning horizon, the lower level of detail, and the more approximate the information (Jonsson and Mattsson, 2009).

At a tactical level, sales and operations planning (S&OP) serves as an example of a planning process that integrates the plans for sales, supply and production into an overall aggregate plan (Noroozi and Wikner, 2017). S&OP was addressed using different concepts since the 1950s, e.g. integrated business planning, manufacturing resource planning, aggregated production planning and demand-supply balancing (Thomé et al., 2012; Feng et al., 2008). That is, S&OP helps to regularly balance the targeted customer demand, shaped by marketing and sales functions, and the supply capacity, shaped by procurement and operation functions (Jonsson and Holmström, 2016). Moreover, S&OP helps to reach cross-functional alignment through integrating strategic, tactical, and operational planning, and through involving operations, finance, and strategic management in the process (Kjellsdotter Ivert et al., 2015). Therefore, S&OP is defined as:

> "*a business process that links the corporate strategic plan to daily operations plans and enables companies to balance demand and supply for their products*" (Grimson and Pyke, 2007, p 323).

Through syncing demand and supply and integrating the hierarchical planning levels and relevant functions, S&OP leads to reaching business targets (Tuomikangas and Kaipia, 2014), such as profit maximisation (Grimson and Pyke, 2007).

The planning horizon of S&OP varies between 6 and 24 months (Stadtler and Kilger, 2002). As for the planning frequency, the process is usually run from a weekly to quarterly basis, while the planning objects are typically product families (Grimson and Pyke, 2007).

S&OP mitigates for uncertainty related to demand and supply (Kjellsdotter Ivert et al., 2015). In this respect, forecasts and other future changes that are relevant from a tactical perspective play a crucial role in shaping the demand that supply needs to match. Here supply is mainly represented by the tactical capacity planning that generates plans for resources (a rough-cut capacity plan) and material (a master production schedule (MPS)). The resource and material plans are based on "formulas" that specify the resources and material required to produce certain products. Resource and material requirements exist in different forms such as product structure, resource profile, bill of materials (BOM) and bill of resources (BOR) (Jonsson and Mattsson, 2009).

The S&OP process typically comprises five main stages including data gathering, demand planning, supply planning, pre-meeting and an executive meeting (Jonsson and Mattsson, 2009; Wallace and Stahl, 2008; Grimson and Pyke, 2007). In data gathering, sales forecasts are generated, while in demand planning, these forecasts are validated, and a preliminary plan for future sales and delivery volumes is developed accordingly. That is, the delivery plan for future sales is based on the forecast, whereby the sales volumes per period the company WISHES to deliver are determined.

As for supply planning, the ability to meet demand is assessed by reviewing the available capacity. Here, functions involved in production like manufacturing and procurement need to develop a preliminary production plan that determines the volumes per period that CAN be produced within the planning horizon of relevance. In the pre-S&OP meeting, the managers from the respective functions involved in demand and supply planning reconcile their individual plans so that demand matches supply given the interdependent constraints and impacts. Finally, the S&OP meeting is conducted to raise the unsettled issues and settle the plan.

Although S&OP is simple in theory, companies vary in how S&OP is implemented. According to Danese et al. (2017), previous literature mainly addresses the implementation that characterises four main S&OP maturity dimensions, including people and organisation, process and methodologies, information technology (IT) and performance measurement.

2.2 Cross-functional integration

Through a literature review, Tuomikangas and Kaipia (2014) discuss the possibility of viewing the way S&OP is organised as the level of integration between different functions participating in the S&OP process. As such, in the next sections, cross-functional integration is discussed in more detail. The first section reviews key definitions of integration and other related constructs in literature before introducing a new perspective of integration, whereby coordination and collaboration come into play. The second section defines the different mechanisms of integrative coordination discussed in literature.

2.2.1 Integration

Integration is highly fragmented in extant research in terms of conceptualisation, definition and operationalisation (Turkulainen and Ketokivi, 2012). While operations management literature typically refers to integration as the different practices used in integration efforts, other research conceptualises integration as an organisational state (Sherman et al., 2005). Similar to several previous works (e.g. Turkulainen and Ketokivi, 2012), this study differentiates between integration and achieved integration drawing on Lawrence and Lorsch's (1967, p 11) definition; "*the state of interdepartmental relations*". Here, integration is conceptualised as achieved integration instead.

Lawrence and Lorsch (1967) identified two main aspects of achieved integration including the quality of the collaboration state that exists among organisational units, and the organisational devices used to achieve it. In other words, a high degree of achieved integration implies that "*the organisation works as a unified whole and the capability of the organisation to transfer, process, interpret and exploit information across functional sub-units is frictionless*" (Turkulainen and Ketokivi, 2012, p 450). Such characterisation emphasises the high efficiency of information transfer across functions and the high exploitation of the transferred information, which has been recognised by other studies (e.g. Galbraith, 1977).

In a higher abstraction level of the integration concept, collaboration and interaction have been suggested as two key dimensions that bring departments together into a cohesive whole, according to Kahn (1996). For him, the way cross-functional activities are structured, e.g. communication exchange, represents interaction, whereas the way in which cross-departmental relationships are affective, i.e. how functions "*work together, have mutual understanding, have a common vision, share resources and achieve collective goals*" (p 139), represents collaboration.

While this thesis accepts collaboration and interaction as integration-related constructs, the way collaboration and interaction relate to integration is still conceptualised differently to some extent. Interaction as a term does not necessarily refer to structured reciprocal actions or influences. In a business context, interaction is "*an occasion when two or more people or things communicate with or react to each other*" (Combley, 2011, p 446). That is, interactions do not impose structuredness as an endogenous characteristic. Therefore, in this research, interactions are instead referred to as mere reciprocal actions that can signal a structured setting of coordination or an affective behaviour of collaboration. In short, CFI is assumed to be possible to achieve either through coordination or collaboration.

The focus of this study is limited to coordination. One reason is that coordination is considerably related to in the extant research concerned with tactical planning (see Tuomikangas and Kaipia, 2014). Another reason is that studying coordination alone requires broad investigation due to the several mechanisms that can be related to coordination. Besides, the suitable approach to study collaboration is somehow different from the approach in which coordination can be studied. Studying coordination within a process implies looking into how the respective interactions are structured. On the other hand, studying collaboration implies looking into the affective aspects that can be related to integration like trust (Kahn, 1996), which needs intensive data gathering at the deep level of individuals. The depth and intensity of data is important to be able to capture evidence like emotions, attitudes, etc. In summary, coordination is a broad area of high relevance for tactical planning, while the nature of collaboration as a concept may need a different research approach making studying both coordination and collaboration within one study a challenge.

2.2.2 Integrative coordination mechanisms

Coordination organises interactions within and among businesses to achieve a common goal. Coordination is "*the process of organising the different activities or people involved in something so that they work together effectively*" (Combley, 2011, p 177). In line with this notion, Chow et al. (1995) defined integration in logistics as the degree of coordinating logistics tasks and activities within a firm and across the supply chain.

Nevertheless, coordination and integration are distinct terms (Oliva and Watson, 2011). While coordination helps to align the decentralised decisions of resource allocation with system objectives by making sure that different decision makers across hierarchies have access to sufficient information and are provided with proper incentives (Narayanan and Raman, 2004), integration typically involves determining these objectives concurrently with the aligning of allocation decisions (Oliva and Watson, 2011). Therefore, integration is a broader concept. However, a plethora of coordination mechanisms has been recognised in integration research.

In integration literature, integrative mechanisms related to coordination are considerably fragmented. According to Turkulainen and Ketokivi (2012), the majority of operation management researchers address integrative practices that can be related to centralisation, standardisation, formalisation, cross-functional teams, task forces, integrator roles and information systems. In this research, these mechanisms help to operationalise the concept of CFI.

2.2.2.1 Centralisation, formalisation and standardisation

According to Chow et al. (1995), centralisation refers to the distribution of power (decision-making authority) or the extent to which decisions are made at relatively high hierarchical levels. Formalisation reflects the extent to which formal rules and standard policies and procedures govern decisions and working relationships independently of the personal attributes of individuals occupying positions in the structure (Daugherty et al., 1992). Standardisation refers to the similarity in the resources used within a firm or the way resources are exchanged across firms (Chow et al., 1995).

2.2.2.2 Cross functional teams and individual integrators

Cross-functional teams (CFTs) and individual integrators are proposed as mechanisms of integrative coordination. Nihtilä (1999) noticed that new product development (NPD) projects are always assigned to cross-functional teams involving members from key departments with specific objectives. In ETO businesses, NPD represents a regular activity within order fulfilment.

According to Mathieu et al. (2014), the way teams are composed and the way team members are located and aligned with each other reflect how integrative these teams are. Apart from that, Nihtilä (1999) found that successful companies dedicate individual integrators in NPD projects to communicate function-specific strategic objectives across departments and facilitate interorganisational interactions with customers and suppliers.

2.2.2.3 Task design and information systems

Hirunyawipada et al. (2010) confirm that the way a task is designed can influence how much these tasks can be integrative. Integrative task design reflects considerable problem-solving orientation, a high degree of information completeness, more possibilities for concurrency between tasks and task cohesion (i.e. division of tasks into specialist and generalist domains) (Adler, 1995; Galbraith, 1974).

Finally, information systems represent the medium in which more and more organisational interactions are enabled. The way information systems support information processing within cross-functional interactions can influence how much these systems are integrative (Daft and Lengel, 1986).

2.3 Synthesis of the framework into a conceptual model

This section synthesises the theoretical frameworks discussed earlier and builds on the conceptual framework of the thesis (Figure 1.3) leading to an extended version, as shown in Figure 2.2. The small circles and squares included in the rectangle represent imaginary units. As perceived, more circles imply more demand and more squares imply more supply capacity. The lines connected to the rectangle represent three states including undercapacity, overcapacity and balance. When there are more circles than squares, a state of undercapacity occurs, and when there are more squares more than circles, a state of overcapacity occurs. When there is an equal number of squares and circles, a balance between demand and supply is obtained.

Relevant constructs are added to the main concepts that interact with complexity and DS balancing. Order acceptance, RCCP, procurement and macro process planning are included under the category of tactical-level decisions and activities. The mechanisms for the CFI category are added, including centralisation, formalisation, standardisation, cross-functional teams, individual integrators and information systems. The maturity dimensions for S&OP are added, including people and organisations, processes and methods, performance measurement and IT.

All tactical-level decision and activity categories, CFI and S&OP influence the detail and uncertainty stemming from demand and supply. In relation to this, the framework includes two complexity driver categories that influence the detail and uncertainty associated with the demand and supply capacity units (i.e. the circles and squares).

Finally, as derived from literature, ETO environments impose challenges to plan engineer resources due to uncertainty. The framework adds two categories that the S&OP process is expected to encounter. Accordingly, the uncertainty areas associated with engineer resource planning can stem either from customer orders or critical competences. The framework is used to organise the results of the research and will be reflected upon later under the results and discussion chapters.

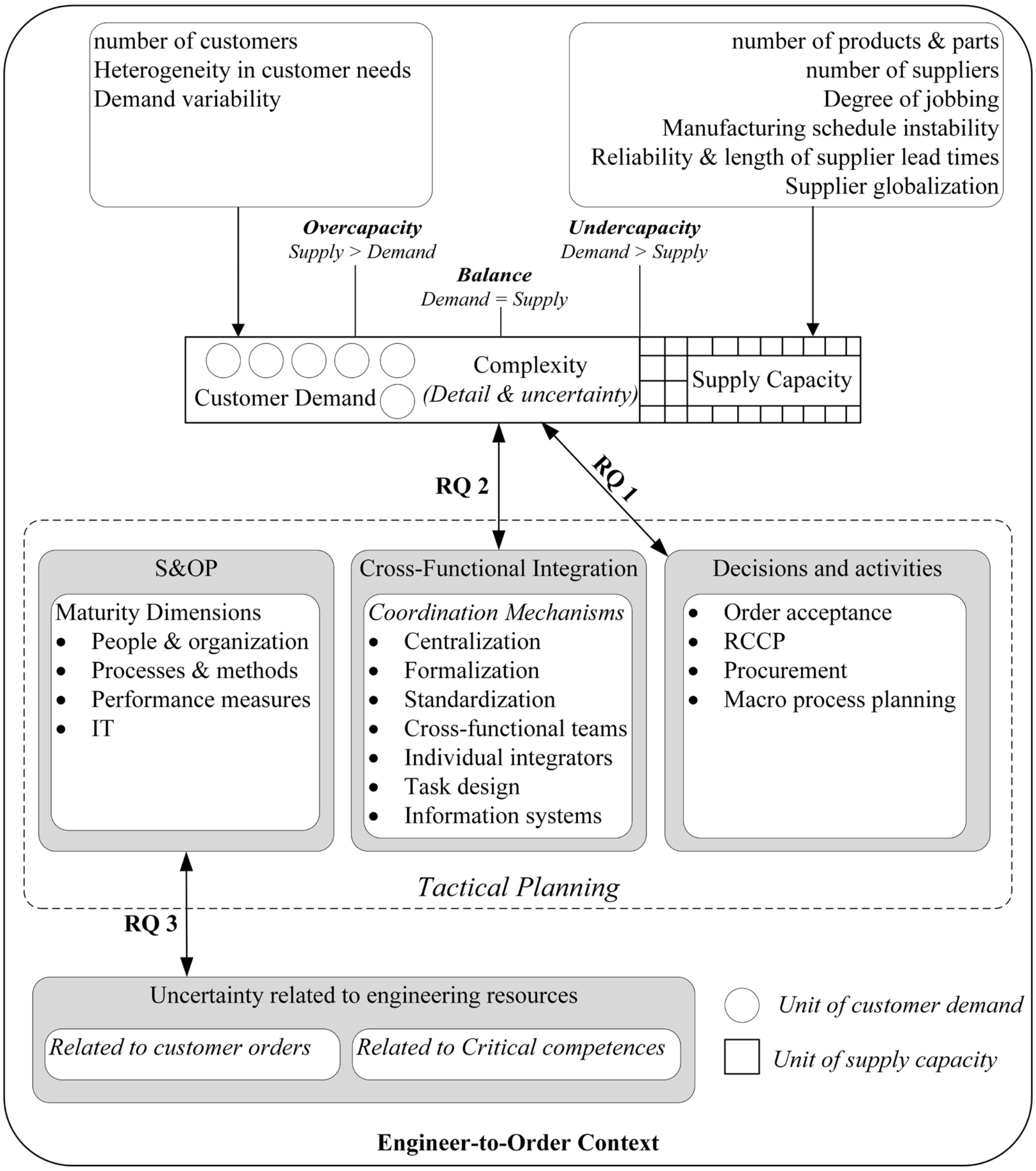

Figure 2.2 Frameworks derived from previous literature on tactical planning, S&OP, uncertainty related to engineering resources and cross-functional integration

3 Research method

This chapter presents and motivates the methods of the research used in the three appended papers. These papers were prepared by conducting the three consecutive studies constituting the thesis. The first section describes the research steps along the timeline. Then, the overall research design used in this thesis is explained. Next, the empirical part associated with each study is described including the study design, case selection, data collection and data analysis. Finally, the questions on validity and reliability that can be related to the three studies are discussed.

3.1 The research steps

The first study in this thesis has been performed as part of a research project called “RePlan”, which was funded by VINNOVA. This research project represented a collaboration between Chalmers University of Technology, Linköping University and other Swedish partners, including two general construction contractors, one recycling company and two IT consulting companies. The first study included a general construction contractor for the case study, while the second study included – in addition to the contractor – a warehousing provider. The third study so far included an aerospace manufacturer. Other parties from the research project have been involved in the first and second study during the formulation of the research objectives and during the validation process.

Throughout the research project, two study phases (preliminary and final) were planned and at least partly conducted for each of the three studies. The third study is still in the preliminary phase. In the preliminary phase of each of the three studies:

- the problems addressed have been drawn from discussions with industrial experts and through reviewing relevant literature,
- the research design and the preliminary conceptual and analytical frameworks have been drawn from the literature review and pilot interviews,
- the case companies have been selected based on the conceptual and analytical frameworks,
- relevant data was collected from each case (see section 3.2 for more details),
- a preliminary analysis was conducted and missing data was supplemented,
- preliminary findings were drawn up from the preliminary analysis,
- and the preliminary findings were reported as preliminary papers (light version).

In the final phase for the first and second study:

- the preliminary papers were presented for and discussed with experts from academia and with the representatives from the selected case companies,
- feedback was provided from the discussions on the preliminary paper, the literature review was adapted and additional refinements were applied on the conceptual and analytical frameworks,
- supplementary data was collected,

- a final analysis was conducted and final findings were drawn up,
- and the final findings were reported as final papers adapted to relevant readership (scientific journals).

A timeline for the research steps is illustrated in Figure 3.1, displaying the sequence of the three studies and the underlying phases.

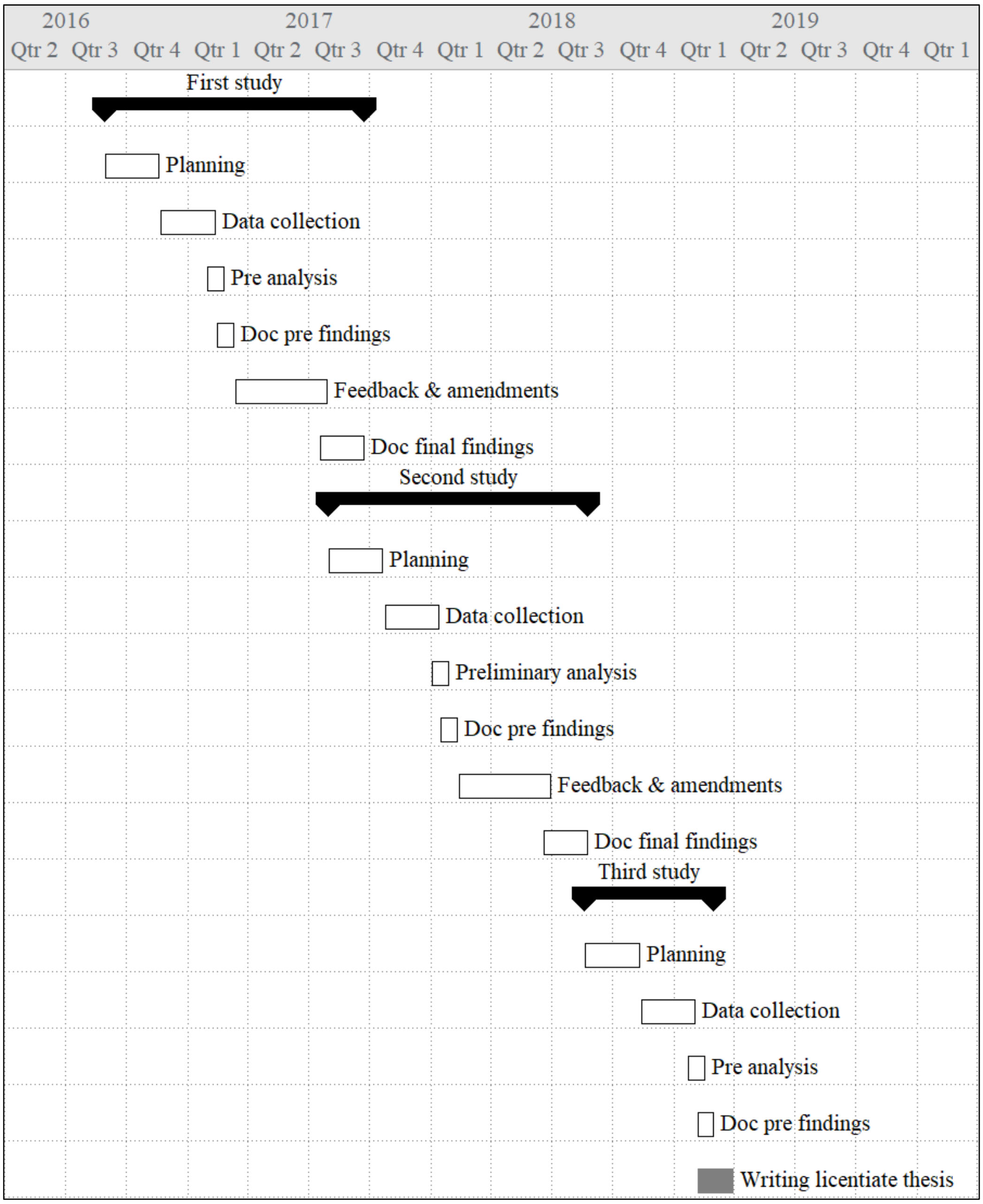

Figure 3.1 The timeline of the research steps in this thesis

3.2 Empirical studies performed

To conduct the three studies, several research methods were used, which are described in the next sections. Each description is related to a separate study including case selection, data collection and data analysis.

3.2.1 Research design

The research of the thesis was designed according to the framework of Maxwell (2012) by developing coherence and alignment between the research questions, the research goals, the conceptual framework, the research methods and the research validity. The interactions between these components are described in the next sections.

3.2.1.1 Study 1: on the effect of tactical planning on ETO demand and supply complexity

Demand-supply balancing as a phenomenon was deemed complex due to the lack of literature. Several studies emphasise that obtaining the balance between demand and supply is a medium-term business objective that realises long-term business ambitions and brings stability to short-termed operations (e.g. Jonsson and Holmström, 2016). However, since DS-balancing as a concept still lacks theories concerning how it can be measured, identifying clearly relevant processes and activities remains questionable. Therefore, this thesis adopted the hierarchical perspective and the notion of tactical planning being the most relevant process for DS balancing. Yet, the boundaries within which activities can be characterised by tactical orientation is far from clear in extant research. In the first place, the complexity of market demands and supply bases across different industries put different prerequisites on the corresponding planning processes. This means that tactical planning should be adapted to facilitate the handling of complexity settings in different contexts.

In ETO settings, very few studies addressed tactical planning. Despite being few, these studies still vary in terms of the way on which the drawing of tactical-level planning boundaries is based. None of these studies explicitly addresses medium-term DS balancing as the baseline of tactical orientation. This called for an in-depth empirical investigation in an ETO setting to further explore what these previous studies addressed but through having DS balancing in the core of the study. And since measuring the effect of activities on DS balancing is perceived as a theoretical gap, the first study addressed the influence of planning activities on the detail and uncertainty stemming from demand and supply.

Even though the previous studies associated with ETO tactical planning focused on different planning activities, they seem to have a central focus on order fulfilment as a main process. Therefore, the order fulfilment process of an ETO-oriented company was empirically investigated through a case study. A single case-study approach was adopted due to the necessity of an in-depth investigation of the influence of the order fulfilment process activities on complexity when balancing demand and supply. The case study identified the sequenced tactical-level planning activities and qualitatively assessed the influence of the key tactical decisions on the demand- and supply-related complexity drivers using detail and uncertainty as dimensions. Accordingly, the case study used as the empirical base of study 1 was designed. The empirical study was the basis for the paper presented at the EurOMA conference in July 2017, which was then extended into a journal article that is appended to the thesis.

The aim of starting with a conference paper was to gain feedback from relevant industrial and academic experts. The feedback helped in refining the conceptual framework and identifying important variations across different ETO settings.

3.2.1.2 Study 2: on the effect of cross-functional integration on ETO demand and supply complexity

Drawing on observations from study 1 and discussions from previous literature, the way tactical planning facilitates DS balancing seems to rest on CFI (Oliva and Watson, 2011). The observations from study 1 shows that to fulfil medium-term customer orders without disturbing the ongoing and future activities, marketing, sales, engineering, operations, supply chain, project management and finance need to interact with each other to capture the uncertainties and to process the details needed as a basis for robust decision making. The way such uncertainty and detail are captured and processed, respectively, depends on how the different functions are integrated throughout the order fulfilment process. Therefore, to go beyond what study 1 discussed, study 2 addressed how different ETO-oriented companies benefit from the CFI embedded in the order fulfilment process to deal with the complexity (i.e. detail and uncertainty) balancing demand and supply.

Study 2 departed from an assumption whereby cross-functional integrative mechanisms should be adapted depending on the level of complexity stemming from ETO demand and supply. Therefore, study 2 was conducted as a case study focusing on how order fulfilment processes use different and similar integrative mechanisms to manage the embedded complexity. As such, two ETO-oriented companies were investigated.

Comparing such differences requires identifying the integrative mechanisms applied and the complexity drivers embedded in each case. Study 2 adopted conceptual frameworks from previous research to capture complexity drivers (see Bozarth et al., 2009) and cross-functional integrative mechanisms (see Turkulainen and Ketokivi, 2012). The frameworks needed a higher level of detailed analysis to ensure evidence clarity for how an integrative mechanism may influence certain complexity drivers. For instance, the claim of having qualitative empirical evidence for the effect of an integrative mechanism like centralisation on the uncertainties and details generated from the breadth of product customisation scope and the number of parallel customer orders had less ambiguity than being related to the main complexity driver, which is the number of customers in this case. Therefore, the case study needed a considerable degree of empirical depth concerned with the order fulfilment processes in question.

The preliminary results of study 2 were first presented at the NOFOMA conference in June 2018. After receiving constructive feedback at the conference, supplementary data was gathered and additional refinements for the contribution of the paper were applied. Accordingly, the working conference paper was extended into a journal article, which is the version appended to this thesis.

3.2.1.3 Study 3: on the mutual effects between S&OP and the ETO uncertainty related to engineering resources

Study 1 and 2 addressed order fulfilment as a process that has tactical influence. However, the cases included in these studies had no established process that formally integrates tactical-level plans across functions, which is why study 3 came into play. Study 3 addressed S&OP in an ETO-oriented setting, which was considerably lacking in extant literature (Kristensen and Jonsson, 2018). Study 3 focused on how S&OP is influenced by and manages engineering resource planning as one of the most uncertain planning activities specifically required to be tactically planned in ETO settings.

Due to the lack of ETO-oriented companies that implement S&OP, study 3 was started as a single case study. The study mapped out the S&OP process using the main dimensions proposed in previous S&OP maturity models (see Danese et al., 2017). The focus was on identifying the areas of uncertainties associated with engineering resources and how the S&OP process helps to capture and deal with these areas.

The preliminary results of Study 3 were compiled as a conference paper that has been submitted to the EurOMA conference that will be organised in June 2019. Like study 1 and 2, presenting the paper at the conference is aimed at gaining more constructive feedback in the pursuit of the guidance concerning how the contribution of the study results can be developed and improved into a full journal article.

3.2.2 Case selection

According to Yin (2017), generalising findings from case studies through theoretical propositions is done rather analytically than statistically.

Generalising results through analysing multiple case studies should be based on a replication logic (Voss et al., 2002). Study 1 and study 3 were based on a single-case approach, while study 2 was conducted through a multiple case study. Accordingly, this section describes the unique characteristics of the single cases in study 1 and 3 and how the replication logic was used in the case selection procedure in study 2.

3.2.2.1 Study 1

For study 1, a single case study was used to explore the tactical-level planning activities and decisions within the order acceptance phase of the order fulfilment process in a selected ETO-oriented company. The case, a Swedish general contractor (SGC), was a regional representative of a strategic business unit of a major player in the Swedish housing market.

Stake (2000) asserts that in-depth analysis of single cases reveals more facets of the phenomenon under study. In turn, exploring the impact of decisions on the complexity that hinders DS balancing requires an in-depth analysis of the integrated activities.

According to Yin (2017), single case studies are suitable if they are unique or extreme in nature. In this respect, the SGC dedicated a project to study how to implement an advanced planning system within the order fulfilment process. The SGC wanted to capture how different specialised engineers and managers should be combined to optimise order (enquiry) selection since certain competences like senior project and site managers were critical. And given that this unique project required a comprehensive evaluation of the current state of the order fulfilment process, we had a revelatory opportunity to take part in this project as operations management researchers.

3.2.2.2 Study 2

Due to the lack of conceptualisation and empirical identification of how CFI is used in an order fulfilment process to deal with the complexity that hinders DS balancing, an exploratory theory-building approach was adopted (Eisenhardt and Graebner, 2007). Drawing on the literature review, CFI is assumed to be represented by integrative mechanisms that coordinate cross-functional interactions, which can in turn be represented by information processing. To explain how and why cross-functional interactions, represented by interdepartmental information processing events, can influence and are influenced by complexity drivers and integrative coordination mechanisms, field research was conducted using a multiple case study approach. In general, multiple case study is suitable to investigate "how" and "why" contemporary events occur (Yin, 2017; Barratt et al., 2011; Eisenhardt and Graebner, 2007; Voss et al., 2002).

In line with the study purpose, selecting companies was based on certain criteria including the ETO orientation and the demand-related complexity. The earlier criterion was based on definitions from literature (e.g. Olhager, 2010; Gosling and Naim, 2009; Earl et al., 2003; Hicks et al., 2001). Accordingly, ETO-oriented companies are project-based manufacturing organisations that, prior to accepting any customer order, need to develop new or apply changes to the current designs of their product(s) and manufacturing process(es) before proceeding to production and delivery to fulfil customer requirements. ETO businesses in general require complex supply settings and genuinely need intensive cross-functional interaction (Earl et al., 2003), which is why the other case selection criterion solely addressed demand complexity. That is, companies were selected based on the difficulty to deal with customer demand represented by number of customers, heterogeneity of customer needs and/or demand variability (Bozarth et al., 2009).

Capturing the complexity drivers and the integrative mechanisms within a customer order fulfilment process required considerable advanced empirical investigation of the respective activities. Therefore, the number of cases was traded off and only two cases were involved. The cases were selected to reflect high contrast in demand complexity. That is, one case had high demand complexity while the other case had relatively low demand complexity.

Two companies that fitted the criteria (their names are concealed), SCC (Swedish Construction Company) and SWC (Swedish Warehousing Company), were first selected. According to Eisenhardt (1989), involving organisations as a sample helps to gain rich insights into the "complexity of the real world".

Before selecting these cases, some screening was done to understand how their tactical-level planning processes can be related to the phenomena under study (CFI and complexity), as recommended by Yin (2017). It is assumed that the comparison across cases can benefit from both heterogeneity and homogeneity. According to Glaser and Strauss (2017) and Yin (2017), cases can be identified by ensuring that conducting the research on them will lead to either highlighting or reducing the differences between the research units. In this research, homogeneity is needed in the main activities of the order fulfilment processes to ensure the comparability across cases. On the other hand, heterogeneity is needed in terms of complexity and applied CFI to enable inference of how CFI mechanisms can be related to the demand- and supply-related complexity drivers. That is, using certain CFI mechanisms solely under certain complexity settings may raise questions concerning the increasing need for CFI and its contingent impact.

Table 3.1 introduces the background of each case. The table shows the relative difference between the cases in terms of the complexity driven by demand and supply. This relative difference was drawn up during screening companies using relevant materials that describe each case's products, customers and manufacturing systems. This was followed by short pilot interviews that revealed confidential figures (e.g. number of current customers, etc.) to validate the relative comparison.

Table 3.1 Case characteristics included in study 2

Characteristic	SCC	SWC
Background		
Industry	Construction	Warehousing
Market segment	Residential buildings	Complete customised warehousing and logistics solutions
SBU level	Regional	Global
Supply chain position	OEM	3PL
Marketing strategy	Complete solutions focused on specific segments	Differentiation through automation
Demand-related complexity drivers		
# of customers	Medium-High	Low-Medium
Heterogeneity in customer needs	High	Low-Medium
Demand variability	High	Low
Supply related complexity drivers		
Potential number of products	High	Low
Potential number of parts	High	Low-Medium
Low volume batch production	One-of-a-kind	One-of-a-kind
Manufacturing schedule instability	High	Low-Medium
Number of suppliers	High	Low
Long and/or unreliable supplier lead times	High	Low-Medium
Globalization of supplier base	Low	Low

3.2.2.3 Study 3

An exploratory single case study was conducted at a multi-technology second-tier aerospace supplier. According to Yin (2017), a single case study can be used to represent a unique or extreme case. The uniqueness of the selected case stems from being an ETO-oriented firm which uses an S&OP process that integrates engineering resource planning. Above all, the case is in line with the scope of the thesis, which is reflected by having an S&OP process that includes engineering resource planning to manage the ETO complexity of the case setting.

3.2.3 Data collection

Several sources of evidence can be used in case research. In the three studies of the thesis, archival records, interviews and direct observations have been used. The following section describes the data collection methods employed in the respective studies.

3.2.3.1 Study 1

The order fulfilment process at the SGC involved representatives from R&D, marketing and sales, procurement and production and project management. Accordingly, eight decision makers were selected as shown in Table 3.2.

Table 3.2 The profile of selected interviewees

Planning orientation	Interviewee	Department	Main Role in order fulfilment
Demand & Supply	Head of R&D	R&D	Directs tender request selection and deployment of advanced construction methods & processes.
Demand	Market Analysis Manager	Marketing & Sales	Analyses geographical market potentials; reports sales performance, competition, and inputs for core & adjacent competences, i.e. digitalisation.
Demand	Head of Partnering	Marketing & Sales	Directs bid preparations for tender requests under partnering, not competitive tendering.
Demand	Head of Key Account Management	Marketing & Sales	Directs the bid preparation process, assigns key account managers to tender requests and makes final decision for selecting & prioritising tender requests.
Supply	Production Manager	Procurement & Production	Validates specs of tender requests against production feasibility and economics.
Supply	Production Development Manager	Procurement & Production	Validates alignment of selected tender requests with production capabilities and reviews designs and delivery plans developed for estimating respective costs and timeframes.
Supply	Resource Planner	Procurement & Production	Assigns bid preparation team members to the selected and prioritised tender requests.
Supply	Project Manager	Project Management	Coordinates bid preparation workflows and documentation and supports production and procurement functions.

In total, eleven 120-minute semi-structured interviews were conducted. Observations were made during twenty project meetings and four workshops. The focus was mainly on the interaction among participants. This helped capture how the interviewees and other key stakeholders discuss options and make decisions. Observing participants helps to describe social situations, while observing systems assists in understanding the underlying structures of a phenomenon (Flick, 2009).

Interviews and observations were supplemented with archival data including worksheets and presentation slides, (financial and annual) reports and written communications among the participants of the order acceptance phase of the order fulfilment process. Secondary documents from Swedish construction associations were used to gather more insights into the common organisational structures, routines, and roles and the common responsibilities of the different key stakeholders assigned to different functions (i.e. design, engineering, etc.). Above all, the observations and secondary data were used to further clarify and validate the main results of the semi-structured interviews.

3.2.3.2 Study 2

Data was collected using semi-structured interviews. Eleven managers across the two selected companies were interviewed. The interviewees represented the different functions involved in the order fulfilment process. The boundaries of the process were based on literature, comprising customer order screening, customisation, workload analysis, reviews and contracting.

The order acceptance phase of the order fulfilment process is coordinated by certain individuals who were interviewed in the two cases. Because SWC is significantly smaller and less complex than SCC, and because it was investigated after SCC, three interviews were enough to collect the required data. The coordinators in both cases helped in identifying the key functions involved in the process and which functional representatives should be interviewed. Primarily, data was needed from functions that cover both demand and supply planning. In the selected companies, these two perspectives were represented by three areas including marketing and sales, procurement and production, and project management. Consequently, at least one key corresponding manager from each area who had relevant comprehensive knowledge and practical experience was interviewed, as shown in Table 3.3.

Table 3.3. The profile of selected interviewees

Company	Planning Orientation	Interviewee	Department
SCC	Demand & Supply	Head of R&D	R&D
	Demand	Market analysis manager	Marketing & Sales
	Demand	Head of partnering	Marketing & Sales
	Demand	Head of key account management	Marketing & Sales
	Supply	Production manager	Procurement & Production
	Supply	Production development manager	Procurement & Production
	Supply	Resource planner	Procurement & Production
	Supply	Project manager	Project Management
SWC	Demand & Supply	Head of solution design	Marketing & Sales
	Supply	Operations manager	Procurement & Production
	Supply	Project manager	Project Management

These interviews revealed process data that captured and validated the application of CFI mechanisms and the complexity drivers stemming from demand and supply using the guidance of relevant literature. Moreover, the interviews helped to identify lower-level complexity drivers adapted to the ETO context. Finally, the managers helped through the interviews in providing insights into how the applied CFI mechanisms (in forms of practices, policies, etc.) helped to deal with the detail and uncertainty generated by demand supply.

Gathering data during the interviews was guided by an interview protocol (see the respective appended paper) that consists of semi-structured questions, which were in turn based on relevant literature. The questionnaire was evaluated by academics with relevant knowledge and modified according to their suggestions (Yin, 2017). The interview questions were posed in English but discussed in Swedish, which means that the data came in Swedish and needed to be translated back to English and validated for reliability.

Unfortunately, recording interviews was not allowed except on two occasions, but notes, impressions and ideas that occurred during these events were collected and added to the case study database (Barratt et al., 2011). Besides, most of the interviews were conducted in the presence of a researcher, which allowed for observations (Voss et al., 2002). Observations added another source of data, which contributes to the validity of the research constructs (Eisenhardt, 1989).

During interviews, conversations helped to study the phenomenon with emphasis on each case's characteristics and other circumstances that might influence the results. Through exploring relevant process events, understanding the mechanisms involved can be developed (Yin, 2017; Closs et al., 2008). Through covering key topics, exploring new and developing areas was possible (Stake, 2000).

The interviews took from 1 to 2 hours depending on the extent to which the interviewees were able to provide reflections. Data collected from the interviewees was then coded into categories.

3.2.3.3 Study 3

Drawing on the study conceptual framework, an interview protocol was developed to collect empirical data. The data was gathered through semi-structured interviews and process-related documents. In total, six interviews were held with an average length of 100 minutes. Three interviews were audio recorded and conducted with one participant, while the other three interviews involved a relevant group of participants. The three group interviews were held with management representatives from the logistics and operations planning function. Then, an interview was conducted with the head of marketing, the S&OP coordinator and a representative from the management team of the engineering function who is well involved in S&OP.

The unit of analysis was the S&OP process, whereas data was mainly focused on explicating the uncertainties associated with engineering resources and how they were addressed (i.e. identified, communicated and minimised) throughout the S&OP process at the case company.

3.2.4 Data analysis

Analysing the single cases (of study 1 and 2) was based on coding the case contents iteratively to identify and categorise the constructs of relevance (Glaser and Strauss, 2017). On the other hand, the analysis of study 2 comprised within-and cross-case analyses. The within case analyses allowed for building the patterns that match the constructs of the respective conceptual framework (Yin, 2017). Using the findings revealed from the within-case analyses, the cross-case analysis derived the study conclusions. This section further describes the analysis procedures used in each of the three studies.

3.2.4.1 Study 1

The study aims to understand how ETO complexity affects the balancing of customer demand and supply capacity in tactical planning, and is managed in the tactical-level planning process. The first step was to map the sequence of activities that constituted the sub-processes suggested by the conceptual model and the information flows within them. These activities were highly integrated into each other as shown in the case description, and being viewed within the separated sub-processes suggested in literature hinders capturing the in-between interfaces. Therefore, the activity boundaries were drawn in line with the order fulfilment sequence, but new constructs that capture these boundaries were introduced after several iterations of inductive coding (Glaser and Strauss, 2017).

One example of the new constructs and how they were developed is procurement. By deconstructing the sub-processes into parallel detailed workflows along the order acceptance phase, procurement activities were found to be divided into two main domains with distinctive objectives. The procurement function first supports in fulfilling the need of reliable engineering capacity within order acceptance. Later, procurement supports in fulfilling the need of reliable capacity and supply for the project execution phase. As such, procurement as a construct was divided into two distinctive constructs with different objectives, order and requirements.

To ensure their relevance to tactical planning, the identified activities needed to have direct influence on the company medium-term objectives disaggregated from the overall business objectives. To identify key decisions, the events where stakeholders had to select one of several options were listed. To ensure their relevance to tactical planning, the decisions needed to have impact on DS balancing and any related complexity driver. To analyse the decision impact on the complexity drivers, evidence from the case data needed to motivate how decisions led to increased/reduced uncertainty and/or detail. Consequently, the analysis findings were discussed and related to literature proposing a framework for DS balancing from a complexity perspective, yielding the first paper appended to this thesis.

3.2.4.2 Study 2

The unit of analysis was the cross-functional interactions throughout the order fulfilment process. To analyse data, a content analysis method was adopted (Voss et al., 2002). By this method, the content of textual data was subjectively interpreted and systematically classified and coded into themes or patterns (Hsieh and Shannon, 2005). In this study, content analysis was conducted with the help of spreadsheets and the analytical framework discussed earlier in the literature review.

The analytical framework helped in the initial categorisation of the interview and observation descriptions. The established categories of complexity drivers were used as main categories under which relevant or supporting texts were related.

The subcategories were developed and structured iteratively to identify the low-level complexity drivers (Glaser and Strauss, 2017).

The established categories of integrative coordination mechanisms were used as sorting categories for the descriptions gathered about the order fulfilment activities. These descriptions related to the cross-functional interaction settings throughout the process, which helped to identify the applied integrative mechanisms and their configurations.

The low-level complexity drivers and the applied integrative mechanisms were identified by descriptively analysing individual cases in an interpretive way based on previous literature. The interpretation was based on studying the process descriptions to make comparisons and distinctions and rank elements based on information processing (Bauer and Gaskell, 2000). This helped to capture the cross-case similarities and differences between the integrative mechanisms adopted to deal with detail and uncertainty. The findings from the analyses were discussed and a model for managing detail and uncertainty through CFI was proposed accordingly in the second paper appended to this thesis.

3.2.4.3 Study 3

Through content analysis, the collected data was analysed and relevant constructs were identified after several iterations of inductive coding (Glaser and Strauss, 2017). Through empirical evidence, several areas of uncertainty associated with engineering resources were confirmed and new more specific areas were suggested as new constructs. The empirical data on how such uncertainties were addressed throughout S&OP, as opposed to the traditional S&OP process (e.g. Wallace and Stahl, 2008), allowed for identifying several requirements of the S&OP process in ETO settings.

3.3 Validity and reliability

Voss et al. (2002) recommended the framework of Yin (2017) to assess the validity and reliability of case research. Thus, Yin's framework was used to assess the validity and reliability of all the studies in the thesis. Accordingly, the next sections describe how the construct validity, internal validity, external validity and reliability were considered for each study.

Voss et al. (2002) defines construct validity as the degree of correctness for the operational measures used to study concepts. Yin (2017) takes another angle and emphasises the importance of using multiple sources of evidence as an indicator of acceptable construct validity. The sources of evidence should serve as a "chain of evidence" through ensuring the traceability of the collected data over time, which is in turn ensured by recording the sequence of data collecting activities and by gaining approval from the key informants concerning the drafts of the case study report. In this respect, Voss et al. (2002) recommends observation as an important source of evidence that can ensure construct validity by confirming the relationships among different constructs.

Voss et al. (2002) defines internal validity as the ability to clearly draw a causal relationship through showing how certain conditions lead to other conditions. Four approaches are suggested by Yin (2017) to ensure internal validity including pattern matching, explanation building, addressing rival explanations and using logic models.

External validity describes the possibility of using the research findings beyond the scope under study, i.e. the generalisability. Generalising findings through case research has been criticised for not being based on enough evidence. However, Yin (2017) proposes logical replication in multiple cases to improve the external validity of case research.

Finally, the reliability of research describes the conditions where the same findings of a certain study can be reached by another researcher if the study is replicated. In case research, reliability implies the replicability of analysis using the same case, which can be ensured using a case research protocol and a case research database (Yin, 2017).

3.3.1 Construct and internal validity

To establish a chain of evidence and ensure construct validity, similar procedures were followed among the three studies. Data triangulation was considered in all the studies to ensure construct validity. According to Voss et al. (2002) and Barratt et al. (2011), triangulation by increasing the sources of data helps to better understand a phenomenon.

Triangulation was done by using both company archival data and direct observations before developing case descriptions as different sources of information to ensure greater accuracy of and, thus, validate the interview descriptions about the order fulfilment process in case of study 1 and 2, and about the S&OP process in case of study 3. In other words, detailed documents describing the order fulfilment process and S&OP process at the respective case companies were studied before and after conducting the interviews. Formal and informal documents about the respective processes such as policies, reports, instructions, guidelines, checklists, presentation slides, etc. were collected to assess the alignment among the interviewees' perceptions and opinions. Whenever potential discrepancies or missing information were discovered, follow-up conversations were conducted with the interviewees via e-mails or phone calls, as suggested by Voss et al. (2002).

When allowed, all the interviews were voice recorded and transcribed within a few days after the interviews. When voice recordings were not allowed, notes were taken, and interview summaries were compiled directly after the interviews. Moreover, interviews were conducted in a certain order that ensured logical data gathering through which the questions about specific areas were posed to the right informants. Supporting documents and archived data were supplemented by the respective company and attached via email or handed over during the interviews. In this way, for each case study, a dedicated database was established. The case descriptions were developed and sent to the key informants for further review. In accordance with the review comments put forward by the key informants, the case descriptions were adapted and finalised.

To ensure internal validity, inferences made on an event that cannot be directly observed from case studies need to be correct (Yin, 2017). In this thesis, the studies mainly rely on such inferences. In study 1, direct observation on the influence of the order fulfilment activities and the respective decision-making process on DS balancing could not be made. Therefore, the interviews focused on the root-causes of DS balancing using the complexity perspective represented by detail and uncertainty as main elements. That is, inferring that DS balancing is influenced by a certain activity or decision was indirectly related based on the evident influence on detail and uncertainty. Drawing the causal links between DS balancing and both detail and uncertainty was based on a theoretical framework. Whether a certain activity or decision influences certain detail and uncertainty negatively or positively was based on both a theoretical framework and the different source of collected data, i.e. interviews, observations and archival data.

Like study 1, study 2 made inferences on the relationship between DS balancing and CFI mechanisms. Again, the complexity perspective came into play through detail and uncertainty. However, study 2 used the collected data about the order fulfilment process in two cases to further specify the complexity drivers and the integrative mechanisms of the respective theoretical frameworks. Using all the collected data, the cross-functional interactions throughout the fulfilment process in each case was mapped, as shown in the appended paper. The map was used to assess the influence of the identified (specific) integrative mechanisms on the identified (specific) complexity drivers in each case. The assessment combined evidence from the archival data and the interviews. Together with the pattern matching with literature, the archival data and interviews enabled cross-case comparisons, which in turn strengthened the internal validity.

Internal validity in study 3 was ensured mainly using pattern matching with literature. The literature about S&OP and ETO operations is well established. Therefore, studying the influence of ETO settings on the S&OP process and vice versa was based on a robust theoretical base. The data about the implemented S&OP process included detailed archival documents describing the latest update of the sequenced S&OP activities, the inputs and objectives of each activity; the decisions and outcomes of each activity; the methods, sub-processes and systems used to perform and support the activities; and the representatives from each function and the moderators (managers) involved in each activity. This helped in mapping out the S&OP process implemented at the case company to more effectively gather relevant data through interviews. Having detailed insights into the S&OP process helps discover the uncommon patterns of the process configuration, which were mainly attributed to several ETO characteristics.

On the other hand, to ensure that correct inferences were made on the influence of S&OP on an ETO setting, the detailed process map was used in addition to the interviews to track how the medium-term needs of engineering resources were captured and addressed throughout the process. S&OP is started by the marketing function to plan demand. This part was well defined and documented at the case company, and thus easier to start with and identify the uncertainties through. Having identified the preliminary uncertainty discussions from the demand planning perspective, the interview with the S&OP coordinator then helped in further exploring and describing the issues from the supply planning perspective. Consequently, more holistic knowledge about the uncertainties related to the engineering resources within the implemented S&OP was captured, which then helped to deep dive into more specific root causes through the interview with the engineering function.

Regardless of the study, the field notes of one researcher were used to summarise the primary narrative of the detailed case study, while the reflections and perceptions of the other researchers were used to corroborate this narrative. When discrepancies were found, the interviewees were referred to.

As for the researcher biases, one researcher analysed the case data using relevant theories, and the researchers jointly assessed and refined the elicited activities and decisions and the impact on complexity.

3.3.2 External validity and reliability

The studies in this thesis do not reflect considerable replication. Study 1 and 2 were conducted as single cases. Even the multiple case study of study 2 only involved two cases. Replication represents an approach to increase external validity in case research (Yin, 2017). However, study 1 and 2 addressed the same unit of analysis, which is the order acceptance phase of the order fulfilment process. Moreover, one of the cases in study 2 was the same case used in study 1.

Study 1 represented an exploratory investigation for the relevance of the order fulfilment process to tactical planning represented by DS balancing, whereas study 2 to some extent used the findings of study 1 and replicated its approach using the same complexity perspective, but with more focus on CFI. Therefore, in this respect, study 1 and 2 can be perceived as an integrated larger study. That is, the external validity of the conclusions in study 1 and 2 was improved through the replication logic used, together with the pattern matching with the theoretical framework used in the within-case analyses.

To strengthen the external validity of study 3, replications by including more cases are needed, which is intended as a continuation step for the post-licentiate period.

As for reliability, a case research database was established and maintained for each study, as discussed earlier. To manage the effects of a priori beliefs when collecting and analysing data, the followed procedures were thoroughly documented. This included direct observations and time and activity logs of the research work including the collected data such as the recordings and transcriptions (or summaries) of the interviews and the note summaries of each workshop and site visit. For each study, a case research protocol was used, which served as the plan and template for data collection.

4 Summary of papers

In this chapter, the three appended papers are summarised, providing an overview of their contents. For more details, please refer to the appended papers.

4.1 Paper 1: Engineer-to-order complexity in tactical demand-supply planning

This paper addresses activities and decisions within the order acceptance phase of the order fulfilment process and assesses their impact on DS balancing to understand how tactical planning is affected by and manages the complexity in ETO settings. A single case from the construction industry is used. A generic process model for tactical planning is proposed and how to manage complexity and DS balancing in ETO settings is discussed. Tactical-level planning activities include order screening, customisation, workload analysis, review and contracting. The complexity originating from demand can be reduced through strategically aligned selection and prioritisation of customer orders, while the complexity originating from supply can be reduced through effective selection of external contributors. Given an ETO complexity setting, DS balancing is enabled through proper changes upon order review to optimise multi-project plans.

4.2 Paper 2: Integrative tactical planning to manage engineer-to-order complexity

This paper is aimed at understanding how the CFI of tactical planning can manage the complexity stemming from ETO demand and supply. A multiple case study explores the complexity and CFI in two companies. The within-case analysis identifies ETO-specific complexity drivers and CFI mechanisms in each case. The cross-case analysis addresses similarities and differences to capture how the CFI mechanisms reduce the detail and uncertainty stemming from ETO demand and supply. The case study identified 15 ETO-specific complexity drivers that can be related to the generic drivers from literature, which further explain how detail and uncertainty change. The breadth of product customisation scope and the lack of resource reliability were found to be the most critical drivers. Several CFI mechanisms were identified, a part of which was found relevant for tactical-level planning activities including centralisation, formalisation and information systems. The mechanisms employed by individual stakeholder integrators are found to be more relevant for the decision-making activities, while cross-functional teams and task design are found to be more relevant for the problem-solving activities.

4.3 Paper 3: Managing the dynamic needs of engineering resources through sales and operations planning

This paper explores the complexity concerned with the need of medium-term engineering considering sales and operations planning (S&OP). The areas of uncertainty and how they are addressed by S&OP are investigated in an engineer-to-order setting. Uncertainties stem from customer orders and critical competences and are minimised through integrating engineering resource planning into S&OP sub-processes and organisation, and through explicating methodologies using IT tools that support scenario planning. To improve the effect of S&OP, measuring short- and long-term performance is recommended, and aligning S&OP with the bidding and organisation development processes is found to be important.

5 Results

The following sections present and discuss the results of each study in the thesis. Each section starts by describing the results and ends with discussing how the results contribute to previous theoretical discussions. Since a paper was developed for each study and since each paper addressed one of the thesis research questions, the next sections serve as responses to the research questions (i.e. section 5.1 responds to RQ1, section 5.2 responds to RQ2, section 5.3 responds to RQ3).

The results of each paper were based on an independent empirical study. The empirical studies were based on the theoretical framework derived from literature and presented in Figure 2.2, reinserted below (Figure 5.1) for reference.

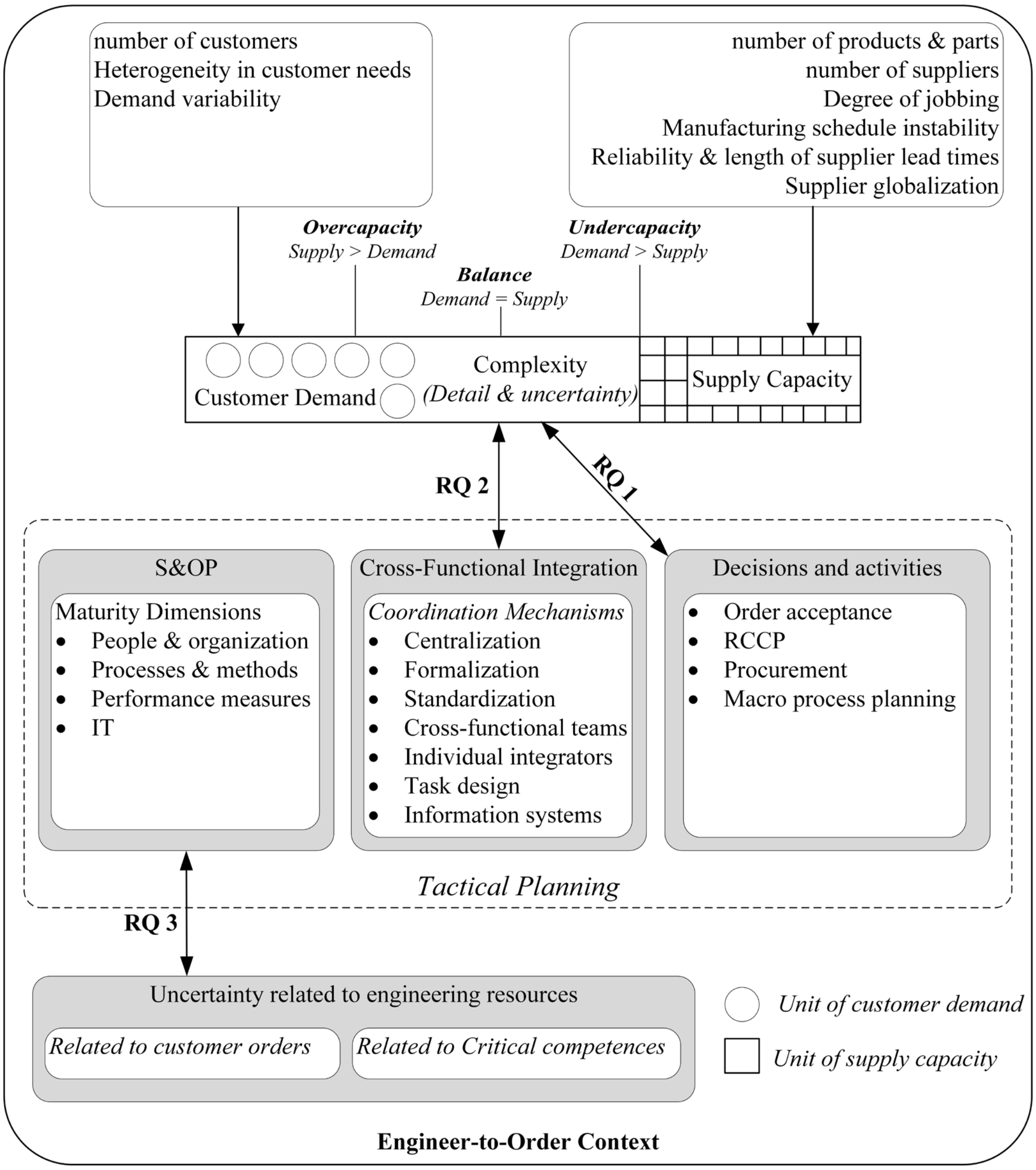

Figure 5.1 Frameworks derived from previous literature on tactical planning, S&OP, uncertainty related to engineering resources and cross-functional integration

5.1 Study 1: Tactical planning in an ETO setting

The first research question addresses the interface between DS balancing through tactical planning and the complexity stemming from ETO settings. The question is restated here for reference:

Research question 1:
How does ETO complexity affect the balancing of customer demand and supply capacity in tactical planning, and how is ETO complexity managed in the tactical-level planning process?

The question has two main parts including how tactical planning is affected by and how does it manage ETO complexity to balance customer demand and supply capacity.

Due to the considerable impact of individual customer orders, tactical-level planning activities focused on the order fulfilment process. The activities are proposed to be part of five consecutive stages including order screening, customisation, workload analysis, review and contracting as shown in Figure 5.2.

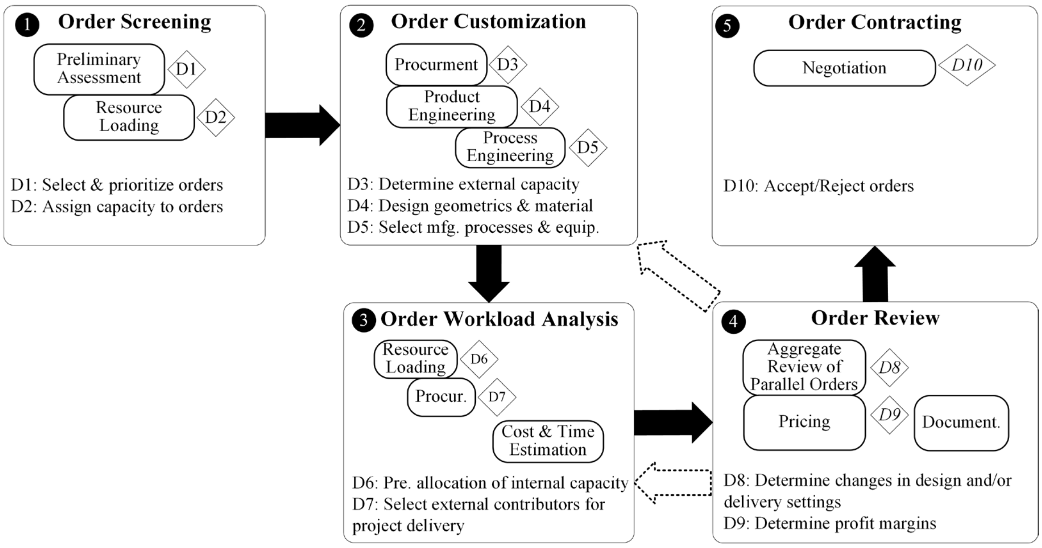

Figure 5.2 Tactical planning in ETO settings

Tactical planning comprises activities of problem-solving or decision-making orientation (see Table 5.1). In problem-solving activities, alternatives related to the delivery process of a customer order are generated and adapted, whereas in decision-making activities, alternatives are narrowed down and corresponding scenarios are developed.

Tactical planning manages complexity through the impact of several key decisions on the detail and uncertainty stemming from demand or supply complexity. Increasing or reducing such detail and uncertainty pushes the actual capacity level away from the DS balance state to a state of over- or undercapacity. Table 5.2 summarises the impact of decisions on the complexity drivers, which points upward and/or downward. Upward and downward relationships refer to increases and reductions in uncertainty and/or detail, respectively.

Table 5.1 Tactical-level planning activities in ETO settings

Process	Problem-solving activity	Decision-making activity
Screening	Preliminary cost and duration assessment	Order selection and prioritisation
	Resource loading for pre-contract activities	Capacity assignment for pre-contract activities
Customisation	Procuring capacity for pre-contract activities	External capacity assignment for pre-contract activities
	Product engineering	Selection of design concepts, geometrics and materials
	Process engineering	Selection of manufacturing methods and processes
Workload Analysis	Resource loading for post-contract activities	Preliminary allocation of internal capacity
	Procuring capacity for post-contract activities	External capacity assignment for post-contract activities
	Developing cost and duration estimates	
Review	Aggregate review of the parallel delivery plans	Determination of changes in design and/or delivery settings
	Pricing customer orders	Determination of profit margins
	Offer documentations	
Contracting	Negotiating customer order terms	Acceptance/Rejection of customer orders

Table 5.2 Decision relationships with complexity drivers

	Complexity drivers							
	Demand-related		**Supply-related**					
Decision	Number of customers	Heterogeneity in customer needs	Number of products	Number of parts	Number of external contributors	Mfg. schedule instability	Reliability and/or length of supplier lead times	Supply base globalisation
D1: Select & prioritise orders	↑/↓	↑/↓	↑/↓					
D2: Assign capacity to order customisation	↓	↓	↓					
D3: Determine external capacity					↑/↓		↑/↓	↑/↓
D4: Design geometrics & select material				↑/↓		↑/↓		
D5: Select mfg. processes & equipment						↑/↓		
D6: Pre. allocation of internal capacity					↑/↓	↑/↓		
D7: Select external contributors – delivery					↑/↓	↑/↓	↑/↓	↑/↓
D8: Determine changes – design/delivery				↑/↓	↑/↓	↑/↓	↑/↓	↑/↓
D9: Determine profit margins								
D10: Accept/Reject orders	↑/↓	↑/↓	↑/↓	↑/↓				

Paper 1 contributes by identifying key planning activities that influence DS balancing in an ETO setting lacking a formal tactical-level planning process. Previous works (e.g. Adrodegari et al., 2015; Carvalho et al., 2015; Hans et al., 2007) address tactical planning in an ETO environment, but this paper elaborates on the crucial role of three main activities in DS balancing including:

- selecting and prioritising customer order/enquiries,
- selecting external contributors,
- and optimising the configurations across the order fulfilment plans associated with the parallel customer orders/enquiries (i.e. multi-project optimisation).

The relevance of these activities stems from the impact of the underlying decisions on DS balancing. By using the complexity dimensions of detail and uncertainty – adapted from Senge (1998) – and the supply chain complexity drivers – reviewed by Bozarth et al. (2009) – to analyse the decision-making impact, paper 1 delivers another major contribution to study DS balancing as a phenomenon. This is reflected in the framework in Figure 3, proposing that DS balancing in ETO settings can be directly managed through multi-project planning given a certain setting of demand and supply complexity, and indirectly facilitated by reducing the uncertainty and detail stemming from such complexity. Reducing the complexity stemming from demand and supply is proposed to be possible through selecting and prioritising customer orders and selecting external contributors, while DS balancing is proposed to be possible through multi-project optimisation.

In relation to multi-project optimisation, several explanations are suggested as contributions to extant literature (e.g. Carvalho et al., 2015; Hans et al., 2007; Giebels, 2000). Multi-project optimisation is aimed at developing an aggregate plan whereby products and manufacturing processes are designed so that synergies among resources are maximised and compromises are minimised across the parallel ongoing and upcoming orders. Such optimisation helps to augment supply and minimise the level of undercapacity as shown in Figure 5.3.

The results confirm the emphasis of Cooper and Budd (2007) on aligning customer orders with the critical competences that provide the competitive advantage to win orders in ETO settings. In ETO environments, tying resources to customer orders typically implies that these resources will be fully dedicated to individual projects for a relatively long time. That is, certain types of resources become more needed then others due to their rareness and uniqueness. Therefore, customer orders should be well selected, and products and processes should be properly engineered so that critical resources are optimally utilised.

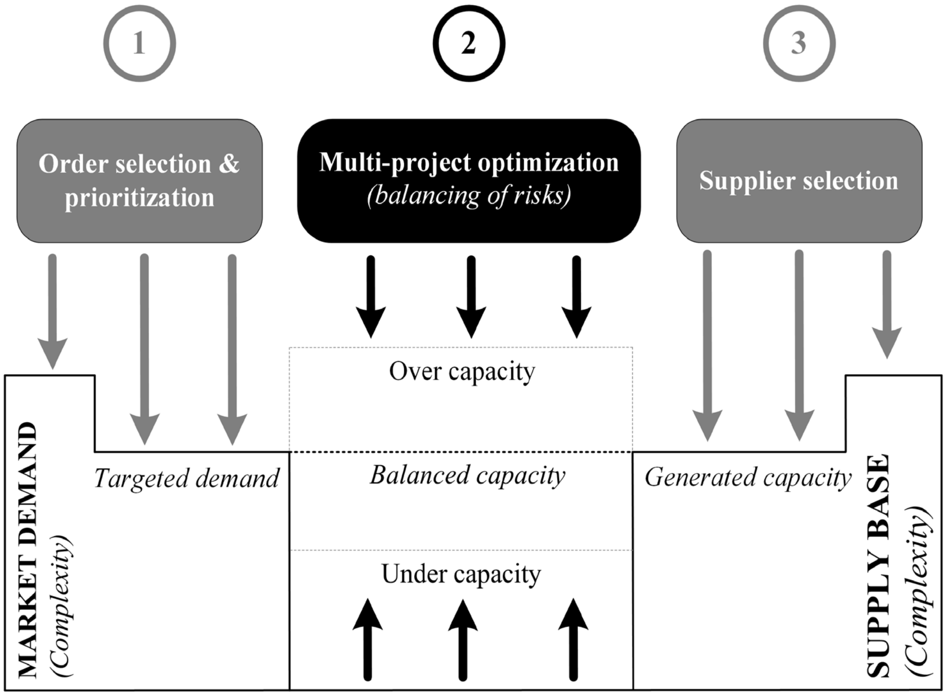

Figure 5.3 Balancing demand and supply through managing complexity and multiple projects

Another (secondary) contribution related to the earlier discussion is the identification of aspects related to three complexity drivers reviewed by Bozarth et al. (2009) including the size and globalisation of the supply base and the supplier lead-time length and unreliability. The suggested effect from having the values of these variables to increase is that both detail and uncertainty increase proportionally. In paper 1, the need for such an increase is identified as another related area of uncertainty. That is, the case shows that there is uncertainty concerning the necessity of selecting several global over local and new over existing suppliers in many projects.

5.2 Study 2: CFI of tactical planning in ETO settings

The second research question addresses the interface between ETO complexity and the CFI reflected from the tactical-level planning activities. The question is restated here for reference:

Research question 2:
How can the cross-functional integration of tactical planning manage the complexity stemming from ETO demand and supply?

The results were divided into three areas: ETO-specific complexity drivers, CFI mechanisms in tactical planning and the influence of the CFI mechanisms on the detail and uncertainty stemming from ETO demand and supply.

Figure 5.4 shows that two out of fifteen ETO-specific drivers seem to repeatedly appear as relevant to many generic complexity drivers. Based on that, the detail and uncertainty stemming from demand and supply seem to be mostly influenced by the two drivers: 1. breadth of product customisation scope and 2. internal resource reliability.

Broader customisation scope lead to more segments (more customers), more heterogeneity in customer needs, more unique products and components, more suppliers and more jobbing leading to greater detail and uncertainty. As for resources, the more reliable the competences in ETO settings, the more complex and the larger the projects these competences can be assigned to. The lack of highly reliable competences leaves two options for compensation: increasing resource reliability (through e.g. outsourcing, training, etc.) and breaking down their critical jobs into tasks that can be carried out by non-critical resources.

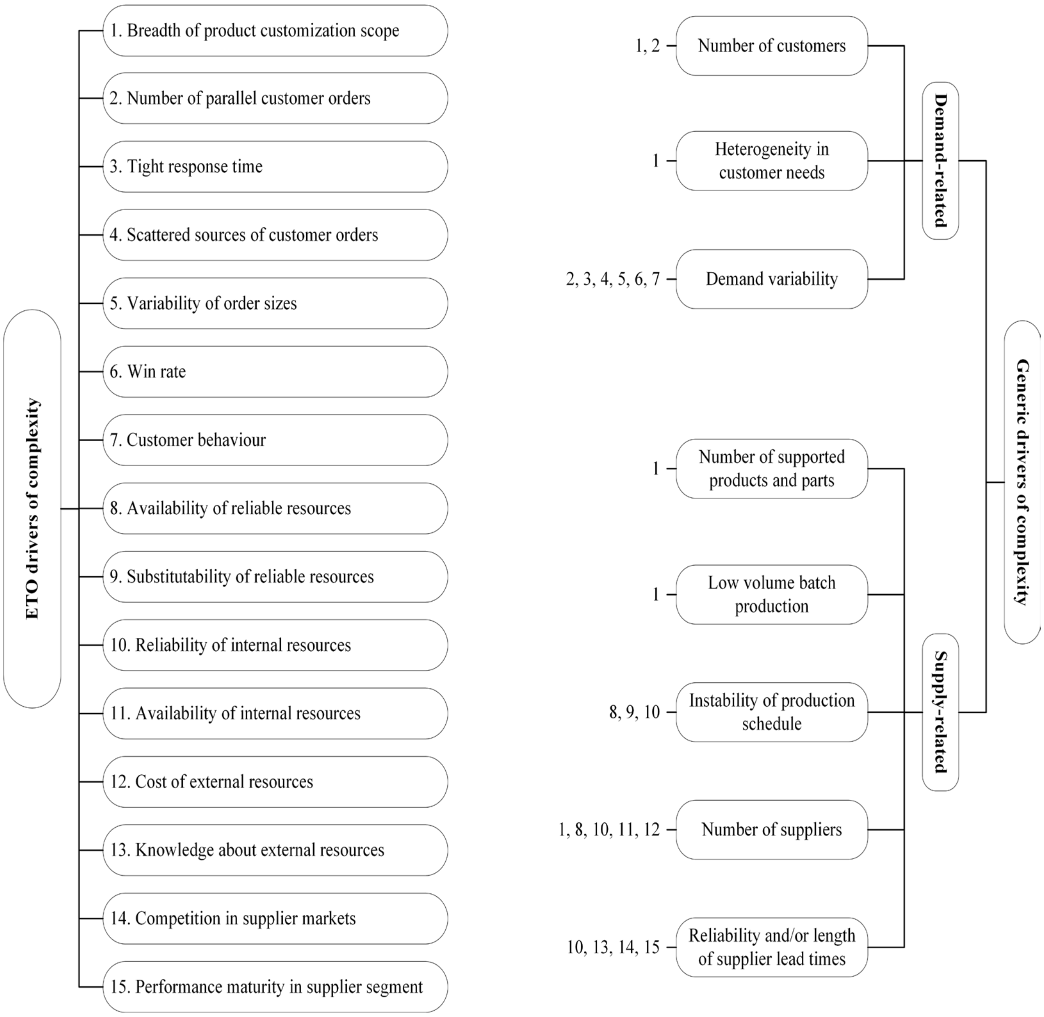

Figure 5.4 Complexity drivers stemming from ETO demand and supply

The CFI (coordination) mechanisms that are used in tactical-level planning activities are presented in Table 5.3.

Table 5.3 CFI mechanisms within tactical-level planning activities

Main and underlying mechanisms
Centralisation
↑ Centralised selection of enquiries and assignment of team members
↑ Centralised selection of customisation and workload analysis options
↑ Long-term relationships with limited numbers of suppliers
Formalisation
↑ Policies and procedures recognise functional interdependencies
↑ Formal process performance measures based on hit-rate, profit margins, resource utilisation, market share and product-specific measures
↑ Formal order fulfilment schedules and plans
↑ Formal regular, structured and well-communicated meetings
Individual integrator
↑ Recruiting individuals with prior experience from customers and interdisciplinary skills
↑ Systematic gathering and using of information about existing or previous customers
↑ Job rotations
↑ Project-based rewarding systems
Cross-functional teams
↑ Co-located and aligned bidding team members
↑ Balanced team composition: size, heterogeneity, tenure, distribution, roles and responsibilities
Task design
↑ Problem-solving orientation of cross-functional tasks
↑ Task information completeness
↑ Task concurrency between design and project operations
↑ Task cohesion: division of tasks into specialist and generalist domains
Information systems
↑ Data management infrastructure: databases and servers to store and retrieve information; companywide IT services (e.g. e-mails, tele-conferences and telephones), applications (e.g. word processing and spreadsheets) and web-based gateways to collect, organise and transmit relevant information)@ OF(
↑ CRM software integrated into customer order databases
↑ IT software for optimising product functionalities

Figure 5.5 summarises the effects of the respective mechanism on the detail and uncertainty stemming from demand and supply given the type of tactical-level planning activity.

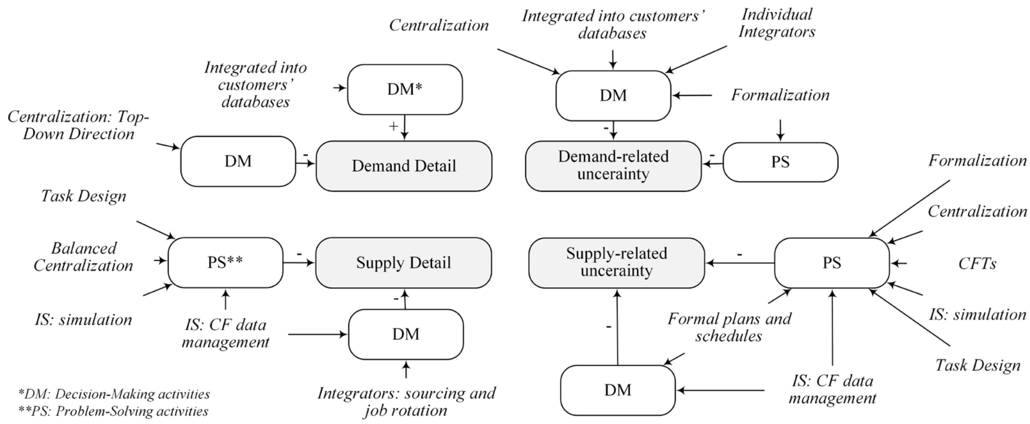

Figure 5.5 Integrative coordination mechanisms to manage detail and uncertainty

By identifying 15 ETO-specific complexity drivers, paper 2 contributes to the generic complexity drivers of Bozarth et al. (2009). Paper 2 specifies customisation scope and resource reliability as the most crucial two drivers that seem to stand behind many generic drivers. In this way, paper 2 confirms the previous work of Closs et al. (2008) and Hicks et al. (2001) whereby broadening customisation scopes introduce more unique products and components and more jobbing in manufacturing. Paper 2 follows on Berry et al. (2011) who attributed the instability in a production environment to unexpected absenteeism and machine failure. Paper 2 adds the lack of competence reliability to these two factors and specifies two options to deal with the lack of reliable competences including enhancing competences and breaking down critical jobs.

Paper 2 contributes to the understanding of the cross-functional integrative role of tactical planning previously, studied by Oliva and Watson (2011), by describing the impact of several integrative mechanisms on the detail and embedded in more complex settings. In contrast with Kahn (1996), paper 2 conceptualises integration as interactions that reflect coordination or collaboration.
Paper 2 operationalises centralisation as a coordination mechanism in line with Chow et al. (1995) to confirm that the authority of selecting customer orders and assigning team members to order fulfilment should be given to decision makers that can validate the strategic alignment of demand. This because centralised decision-making leads to systematic exclusion of options.

Following on Nihtilä (1999), paper 2 elaborates on the important role of integrator stakeholders in inter- and intra-organisational coordination describing that they facilitate the learning process about new and existing customers. The results describe how sourcing and job rotation addressed by Pagell (2004) can serve as integrative mechanisms to increase supply flexibility. Paper 2 is congruent with the extant literature (e.g. Sherman et al., 2005) emphasising the integrative role of establishing long-term relationships with fewer suppliers. The paper results emphasise the positive effect of the mechanisms discussed in other studies such as formalising process task objectives and instructions (Emery, 2009), co-locating team members (Galbraith, 1974), balancing team composition, problem-solving orientation of cross-functional tasks, task information completeness and task concurrency and cohesion (Hirunyawipada et al., 2010).

Paper 2 emphasises the often-overlooked integrative role of information system capability to optimise product functionalities and to serve as a platform to test solutions. The results confirm the benefits discussed in previous literature (e.g. Kjellsdotter Ivert and Jonsson, 2014) for having advance information system support in tactical planning.

5.3 Study 3: S&OP in an ETO setting

The third research question addresses the interface between S&OP and the uncertainties associated with the dynamic medium-term needs of engineering resources in an ETO environment. The results are presented in this section next to the research question that is restated below for reference:

Research question 3:
How does S&OP manage the complexity associated with engineering resources in an ETO environment?

The results describe the areas of uncertainty related to the medium-term needs of engineering resources and how these areas are addressed through an S&OP process used in an ETO setting. Given that uncertainty can either originate from demand or supply, the areas of uncertainty are related either to customer enquiries or critical competences.

The areas of uncertainty related to customer enquiries that influence the medium-term need for engineering resources include:

- the sources and timing of enquiries,
- enquiry specification,
- probability of winning contracts,
- and customer reliability.

S&OP manages such demand-related uncertainty through more frequent (e.g. monthly) and cross-functional planning of demand that is based on reliable quantitative and qualitative forecasts and through assumption tracking. S&OP interacts with the bidding process to support demand planning through relevant information about customers and enquiries.

The areas of uncertainty related to critical competences include:

- customer reliability,
- external competence availability,
- competence quantity,
- competence qualification period,
- competence type,
- inter-resource equivalences,
- and internal competence availability.

S&OP manages such supply-related uncertainty through more frequent (e.g. monthly) and cross-functional planning of engineering and production resources supported by proper planning methodologies, sub-process integration and supportive information systems. S&OP interacts with the organisational development planning process to support the planning process of engineering resources and production in capturing the availability of internal and external competences and in identifying the inter-resource equivalences that increases capacity planning flexibility.

Paper 3 contributes to how S&OP is adapted to ETO environments, which is understudied in extant literature according to (Kristensen and Jonsson, 2018). The paper contribution rests on how to manage ETO challenges through the S&OP process, in terms of people and organisation, process and methodologies, and performance measurement. Paper 3 contributes to the importance of having S&OP and other processes like the bidding process and the organisational development process integrated in this context.

The frequent engineering changes caused by ETO demand calls for incorporating a function for identifying and tracking the medium-term needs of engineering competences in addition to what has been referred to in previous literature (e.g. Wallace and Stahl, 2008) as a traditional S&OP organisation.

However, within the engineering functional organisation, the hierarchical gap between management levels can be reflected from limiting the respective cross-hierarchical communication to certain escalation conditions. When this applies, top managers are often not able to question such escalations and thus delay related decisions as they are not fully aware of the grounds on which the identification of engineering needs were based. This corresponds to a general need and absence of early communication of uncertainties and structured communication of assumptions as part of a demand management and S&OP process (APICS, 2019). Such need of early and structured communication is critical in ETO environments. In accordance with the cross-functional integration framework of Oliva and Watson (2011), S&OP may enable improved engineering information quality and constructive engagement even within the engineering function – cross-hierarchically.

As for the processes and methodologies used in S&OP, to address the uncertainty areas concerned with engineering resources in ETO settings, paper 3 agrees with Tenhiälä (2011) that more structured/advanced methods of capacity planning are required compared to other contexts. The lack of using systematic methods to plan capacity for job shops was attributed to the practitioners being often unaware of the possibilities RCCP methods can bring. This applies to the identification of engineering needs and the lack of method transparency hindering quick decisions by higher-level managers and does not allow for establishing a consistent engineering planning process within and across functions and business divisions. Apart from that, there seems to be a strong requirement on the integration between the key sub-processes of S&OP (i.e. demand and supply planning) in ETO settings to be able to run the S&OP cycle on a monthly basis despite the extra need of continually identifying engineering needs. Paper 3 suggests that the integration between demand and supply planning is enabled through a matrix organisation that takes the form of product groups, which in turn serve as collaborative cross-functional platforms. The cross-functional teams from the respective product groups need to be involved in all the demand and supply planning events of S&OP to ensure that both planning processes are integrated throughout the process.

IT has been recognised in several S&OP literature as a key process enabler in many contexts, and paper 3 shows that ETO settings are not an exception. The dominant type of information that can be made available in ETO settings is highly descriptive due to the uniqueness and ambiguity embedded in demand. Manipulating and processing such types of information requires considerable manual human work as information systems are not yet mature enough to automatically arrange descriptive information into systematic codes (Evers, 2018). Instead, paper 3 shows that the information systems used in ETO environments for S&OP should at least enable intuitive explicating of the ad-hoc approaches used by individuals to define the required engineering workload given a certain demand, the required type and quantity of engineering competences given a certain workload and the possible allocation(s) of competences to fulfil the requirements of a certain workload given their availability. Besides, ETO environments are surrounded by several risks and assumptions such as engineering critical resource absenteeism, and IT tools that support scenario planning are much needed under such circumstances. High-performing firms use scenario planning in S&OP (Danese et al., 2017). The scenario-planning support for S&OP in ETO settings needs to enable modelling of the consequences of recruiting new engineers, hiring consultants and reorganising the engineering resource base as these activities are frequently performed. Consequently, paper 3 indicates relatively high IT needs for S&OP in ETO settings, already at lower maturity levels.

As for S&OP performance, paper 3 shows an evident lack where limited performance indicators are used such as scheduling adherence and forecast accuracy. According to Hulthén et al. (2016), the performance of S&OP can be measured by measuring the efficiency of, for example, respective meetings. Meetings are highly important to make timely decisions in ETO settings, especially when it comes to approving the recruitment of additional engineering competences. This is because certain engineering competences need long-lasting preparation and training before they can be properly utilised. The S&OP process by large is more complex in ETO settings (e.g. more functions involved, more supply planning activities) which may motivate a need for measuring process efficiency.

Finally, the case emphasises the importance of tightly integrating certain planning processes in ETO contexts. Since the majority of ETO markets are based on tendering (Hicks et al., 2001), the bidding process plays a crucial role in shaping the medium-term demand. This calls for having S&OP and bidding highly integrated. Similarly, the lifecycle of products influences the timing and volume of future demand, which is extremely important for ETO environments as discussed earlier, and thus needs to be tightly integrated into S&OP. Apart from that, S&OP outcomes should be integrated into organisational development plans as S&OP captures on a monthly basis the potential future competence gaps that the organisational plans need to be aligned with.

6 Discussion and further research

In this chapter, the main contribution related to the overall thesis purpose and research questions is discussed. The discussion then extends to the limitations of the research and the potential areas for further studies.

6.1 Thesis contribution

The purpose of this thesis is to expand the knowledge about how tactical planning contributes to balancing customer demand and supply capacity in ETO settings. The thesis results contribute to two main types of ETO settings. The first type is when no formal process for tactical-level planning activities is established to balance demand and supply, while the second type is when S&OP is implemented. Paper 1 and 2 addressed RQ 1 and 2 respectively to contribute to the first type, while paper 3 addressed RQ 3 to contribute to the second type.

Figure 6.1 shows an overview of the thesis contribution in relation to the thesis purpose. The figure shows the constructs identified within the theoretical frameworks. These constructs were elicited using theoretical guidance and empirical evidences.

Figure 6.1 suggests that in ETO settings where no formal tactical-level planning process is implemented, customer demand and supply capacity are balanced through the impact of tactical-level planning activities and decisions, and through the impact of CFI mechanisms on the complexity stemming from demand and supply. This impact on complexity is represented by changing the degree of detail and uncertainty stemming from demand and supply with which ETO firms need to manage. When S&OP is used to balance demand and supply, different areas of uncertainty need to be addressed in ETO settings (as shown in figure 6.1) which have implications on the S&OP maturity dimensions including people and organisation, processes and methods, performances measures and information technology.

In ETO settings where no formal tactical-level planning process is used, the results of paper 1 and 2 were based on a complexity perspective to elaborate on the phenomenon of DS balancing. That is, the results of paper 1 and 2 expand the knowledge about how activities, decisions and mechanisms help to manage the complexity (i.e. the degree of detail and uncertainty) stemming from ETO demand and supply. As shown in Figure 6.1, when tactical-level decisions and CFI mechanisms lead to lower degrees of detail and uncertainty, DS balancing is facilitated, and obtaining a DS balance is more possible. When these decisions and mechanisms lead to greater degrees of detail and uncertainty, DS balancing becomes more difficult and falling into a state of undercapacity or overcapacity becomes more probable. For instance, decisions like supplier selection can increase such complexity by increasing the total number of suppliers to be managed in all projects (i.e. by embracing more detail to coordinate), or by increasing more suppliers with lower lead-time reliability (i.e. by embracing more uncertainty to handle). As Figure 6.1 suggests, making such decisions in a way that adds detail and/or uncertainty to demand and/or supply makes DS balancing more difficult to obtain and makes under- and overcapacity more likley to occur. Failing to capture the negative influences of adding unreliable suppliers to the supply base, such as delays, means failing to observe that the current supply capacity is not enough to meet the customer demand leading to undercapacity. On the contrary, overestimating such negative influences makes companies dedicate excess resources and suppliers, which leads to overcapacity. In this way, the findings of paper 1 provide information about the domain of tactical planning and the potential DS balancing impact that can be further built on.

Similarly, Figure 6.1 suggests six main types of CFI mechanisms that can lead demand and supply to be balanced or unbalanced (i.e. under- or overcapacity). For instance, making the decision power of customer order selection exclusive to individuals with proper knowledge about strategic alignment and marketing serves as a centralisation mechanism that helps to manage the complexity stemming from ETO demand and supply. The more centralised the customer order selection, the less the demand (detail and uncertainty) has to be processed cross-functionally. By allowing few relevant individuals to validate the order selection process, a narrower and more relevant product customisation scope is allowed, which minimises the overall number of products and customers leading to better conditions for DS balancing.

Figure 6.1 suggests that the RQ2 arrow is bidirectional, meaning that the complexity influences the ways in which CFI mechanisms need to be applied. For instance, centralising design decisions is found to be relevant in terms of the impact on complexity. However, in some ETO industries, engineering functions can be too large in size that it makes such centralization very challenging to apply. CFI mechanisms are considered to help in managing the complexity stemming from demand and supply when the detail and uncertainty related to any ETO-specific complexity driver can be influenced by these CFI mechanisms. To better understand such contingency, the ETO-specific drivers of the generic complexity drivers discussed in literature were identified, as shown in Figure 6.1 in the upper box with two arrows pointing towards two lower boxes. Learning about the ETO-specific drivers is important in understanding the impact of CFI mechanisms. Figure 6.1 shows the ETO-specific drivers with two arrows pointing towards the generic complexity drivers related to demand and supply. The arrows suggest that one or more ETO-specific complexity drivers can influence one or more generic complexity drivers. For instance, the broader the product customisation scope, the more the number of products and parts, and the more the customers.

When using S&OP as a formal tactical-level planning process, the focus on complexity is limited to the uncertainty stemming from the dynamic medium-term needs of engineering competences. Above all, the S&OP process essentially serves as a cross-functional integrative platform that explicitly addresses DS balancing through synchronised medium-term demand and supply planning. The RQ3 arrow in Figure 6.1 is bidirectional pointing towards both S&OP and several areas of uncertainty related to engineering resources. One example of a relevant area of uncertainty is the timing of customer enquiries that is highly important for preparing the engineering resources that will be needed within the medium-term. Given that the acquisition and preparation time of such resources may extend to longer periods, being certain about the timing of future customer orders as early as possible is highly important. In this respect, Figure 6.1 shows that, among other important aspects, the integration between the S&OP process and the bidding process is found to be important. In this way, the results of paper 3 contributes to the thesis purpose by expanding the knowledge about how a formalised tactical-level planning process like S&OP needs to be adapted to live up to the complexity imposed in ETO settings.

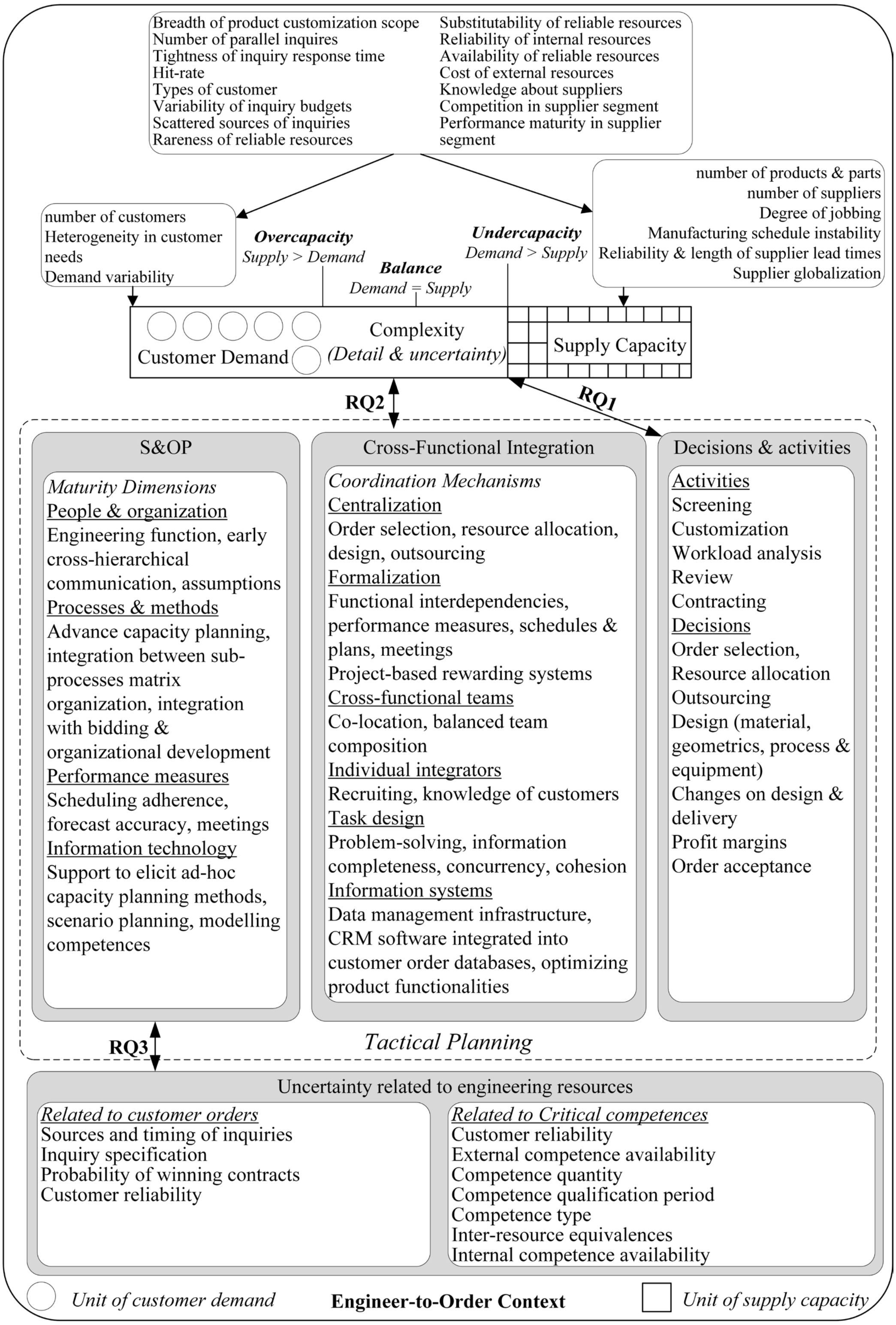

Figure 6.1 Contributions to previous research and the purpose of the thesis

6.2 Further research

This thesis adopted a highly explorative approach to study DS balancing through tactical planning in ETO settings. Relevant previous research lacks clear demarcations of tactical-level planning activities and decisions in ETO environments. The studies of the thesis, thus, prioritised depth over breadth to learn about tactical planning in ETO environments, focusing on few rather than many cases. Having proposed a generic model for tactical planning that can be built on (i.e. the activities listed in Figure 6.1), the focus of future research can shift to the broad approach focusing on many ETO cases to capture the variations in tactical-level planning processes.

The proposed process model comprises activities like order screening, customisation, workload analysis, review and contracting. The stages are similar with the S&OP stages addressed in literature (e.g. Wallace and Stahl, 2008). Therefore, future research comparing the proposed process model with established S&OP examples from ETO environments helps to further explore the prerequisites of DS balancing in such complex settings.

The thesis findings assume that tactical decisions (i.e. the decisions listed in Figure 6.1) and the way the tactical-level planning activities are configured determine whether the detail and uncertainty stemming from complexity drivers increase. For instance, selecting large complex customer orders implies more detail and uncertainty to process. Instead of just indicating that detail and uncertainty may increase or decrease, future studies that model the quantitative effect of decisions and activity configurations, where key variables are linked, will help to capture the relative weights of decisions and activities, not only the effect they have on detail and uncertainty.

The findings suggest that engineering competences in ETO settings (uncertainty related to engineering resources in Figure 6.1) should be given more attention due to the criticality and contingency of their lead times. The cases included in this thesis often fail to identify the multifaceted utilisation of engineering resources (referred to in Figure 6.1 as inter-resource equivalences). Therefore, modelling and optimising studies may address the possibilities to equivalently combine various seniority levels and skillsets with minimum compromises. Modelling critical resource flexibility helps to improve RCCP in general (Hans et al., 2007). Such optimisation may investigate options based on critical and non-critical resource availability and configurability.

In this thesis, integration was conceptualised to have two dimensions including coordination and collaboration. Due to coordination being commonly referred to in the tactical planning literature (e.g. Tuomikangas and Kaipia, 2014), only coordination was considered to narrow down the research scope as reflected from the content in the CFI box in Figure 6.1. This raises a question concerning the potential impact of the collaboration mechanisms on detail and uncertainty, which is recommended for future research to provide complementary answers. Furthermore, the identified coordination mechanisms are driven from highly fragmented integration studies and the categorisation of the mechanisms may benefit from further refining replications.

Finally, having learnt about the important aspects of S&OP from one single setting of ETO – as suggested by the content of the S&OP box in Figure 6.1 – allows for more guidance in any future data gathering seeking more answers, which probably motivates a need for a more inclusive approach focusing on more ETO cases that work with S&OP in various complexity settings. Further, S&OP seems to have cross-hierarchical integrative potentials within large engineering organisations, which is manifested by improved information quality and constructive engagement and, thus, suggested for future research. Another trajectory is to more deeply study the requirements on and the potentials of one or more S&OP dimensions (the underlined content in the S&OP box in Figure 6.1) to manage one or more areas of uncertainty related to engineering resource planning.

7 Conclusions

The purpose of this thesis is to expand knowledge about how tactical planning contributes to balancing customer demand and supply capacity in ETO settings. The thesis addressed both informal and formal tactical-level planning processes. The importance of DS balancing in this context stems from the substantial costs incurred when over- and undercapacity scenarios occur. From a theoretical viewpoint, tactical planning in ETO settings is understudied, specifically in terms of how the process configurations facilitate DS balancing.

The thesis research started from the existing knowledge on tactical-level planning activities in ETO settings and involved previous research from related fields including supply chain complexity, CFI and S&OP. In parallel, the thesis research observed the problems as presented in relevant industries through the companies involved in the research project of which the author was part, and through recommended directions from previous research. Consequently, previous research about supply chain complexity allowed for contributing to extant literature about planning in ETO settings through introducing the dimensions of detail and uncertainty that helped to more explicitly capture the effect of planning activities on DS balancing. Further, the adopted complexity perspective allowed for eliciting several variables that are specifically relevant to the planning environment of ETO settings. The research about CFI helped to understand how several mechanisms can be applied on the planning activities in ETO settings to change the effect of these activities on DS balancing.

Having the detail and uncertainty as indicators that increase or decrease depending on the consequences of the planning activities of S&OP serves as a new perspective for how to understand the S&OP effect on DS balancing in more detail. Moreover, this perspective helped to understand more about the requirements of DS balancing imposed by certain complexity settings (i.e. the areas of uncertainty related to engineering resources) on the S&OP process.

In line with the thesis purpose, three research questions were addressed by three studies focusing on tactical-level planning activities and decisions (Study 1), CFI (Study 2) and S&OP (Study 3). Study 1 was designed as a single case focusing on how tactical-level planning activities and decisions are influenced by and manage the complexity stemming from ETO demand and supply. Study 2 was designed as a multiple case study focusing on the cross-functional integrative role of tactical-level planning activities in managing the complexity stemming from ETO demand and supply. Study 3 was designed as a single case study focusing on how S&OP manages the complexity associated with the engineering resources in an ETO environment.

The study on tactical-level planning activities and decisions was designed as a single case to improve the understanding of what tactical-level planning activities and decisions are and how the decisions can facilitate DS balancing through managing the detail and uncertainty stemming from ETO demand and supply. A conceptual framework of tactical planning in ETO settings was synthesised as a guiding reference to develop a more detailed process model using empirical data from an ETO company. The results provide knowledge about how the tactical-level decisions influence complexity and how they influence DS balancing given ETO complexity settings.

CFI was studied using multiple cases to improve the understanding concerning how tactical planning can reduce the detail and uncertainty stemming from ETO demand and supply. The result of this study provides knowledge about relevant integration mechanisms and ETO-specific complexity drivers and contributes to the research by developing a holistic framework proposing the effects of each mechanism on the respective activities. An important observation is that centralisation and formalisation can reduce detail and uncertainty regardless of the type of activity in question, which is why it is recommended to start with them whenever complexity grows in ETO settings.

The study on S&OP, focusing on the uncertainty areas associated with engineering resources, makes it clear that S&OP dimensions should be adapted to meet the requirements of ETO environments. The study provides more knowledge about the ETO planning environment by identifying eleven areas of uncertainty associated with engineering resources, which can originate either from customer enquiries or from critical competences. To mitigate for these areas of uncertainty, the S&OP organisation needs to integrate an additional function concerned with engineering resource planning, which is well integrated and involved early on when demand planning is triggered. In ETO settings, the need for IT and information sharing is relatively high even at lower S&OP maturity levels.

The thesis contributes to practical aspects by providing guidance to tactical-level planners in ETO environments concerning the areas of improvements to consider when reconfiguring and upgrading the planning process to manage complexity. The thesis framework shown in Figure 6.1 helps practitioners to understand the most important activities and decisions that are relevant to tactical planning in settings lacking a formal tactical-level planning process. The framework provides insights into how to sequence and configure such activities and decisions in line with the firm's specific need for CFI to manage certain complexity settings. Finally, in ETO settings where S&OP is used, the framework provides S&OP planners with insights into how to adapt the S&OP process configurations to better manage the uncertainty stemming from engineering resources.

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